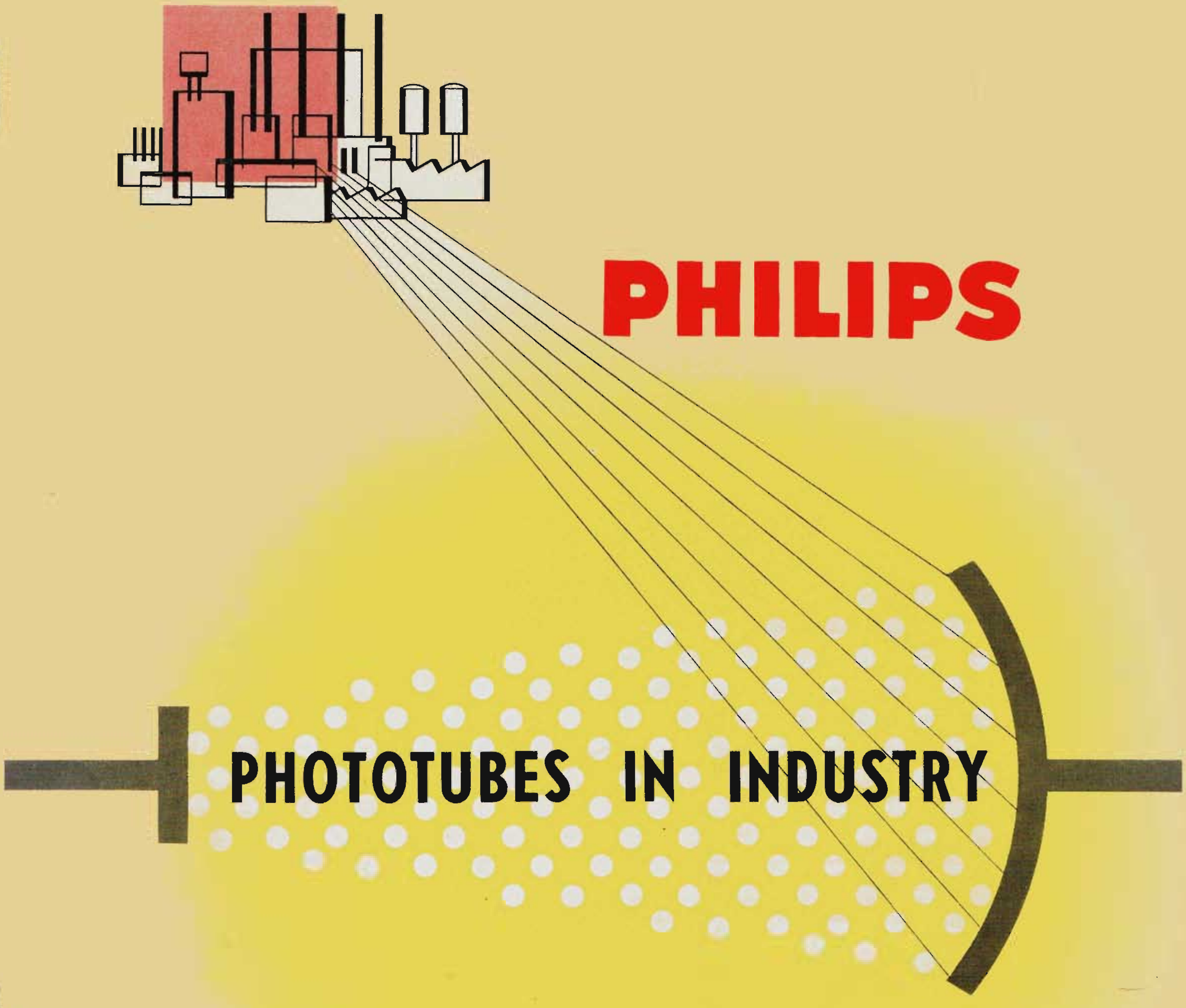
PHILIPS



PHOTOTUBES IN INDUSTRY

PHILIPS ELECTRON TUBE DIVISION

PREFACE

Most inventions of this technical age serve to assist or replace human effort, be it physical or intellectual. There are several mechanical and electrical devices for amplifying human strength or replacing human labour. Microphones and amplifiers augment the sense of hearing, while loudspeakers amplify the power of the human voice. Telescopes and microscopes are an aid to the sense of sight, while photo and film cameras in a certain way further the ability of visual memory.

All these devices are a reinforcement to man. He uses them in cases where a given task can be performed in a more efficient way with the aid of mechanical or physical implements.

The phototube with its supplementary electronic equipment constitutes a device of a higher order, because it acts by itself. It looks and watches; it even partially replaces the reflex actions of the human nervous system, without human aid. Once it is installed anddirected in its duty,it is a never tiring and never sleeping electronic supervisor, and when the phenomenon it is to watch for occurs, it can give a signal or make a huge machine stop or be set in motion, according to the work it is required to do.

The phototube is no novelty. It started its career some thirty years ago. This magic device, made of a little glass, some metals and a tremendous amount of skill, which revolutionized the sound film in one stroke, was bound to penetrate into industry. Here, however, its application was a more gradual evolution because in the beginning even the most progressive of mechanical engineers only hesitatingly introduced the phototube into their kingdom of force and power. Men were needed with an interest in, and with a knowledge of, both mechanics and electronics; teams of mechanical and electronic engineers had to be formed, before the younger technique could take its place on an equal footing with the mechanical and electrical industry.

Especially during the last decade, when tremendous industrial problems had to be solved in the shortest and most efficient way, co-operation between mechanical and electronic engineers came to full development.Due to electronics,which proved a formidable ally, production could be accelerated and multiplied in an unprecedented way. With electronics, general interest focuses in particular on the phototube, because its application brought the solution of hitherto insoluble technical problems. This documentation, which contains information, circuits and suggestions on industrial phototube applications, is offered to the progressive electronic equipment maker in order to direct his attention to this but partially explored field of action and source of profit. Additional and specific assistance for solutions of problems that might arise during development of phototube apparatus will be gladly given.

CONTENTS

PART 1

General information

HIGH-VACUUM PHOTOTUBES

Phototubes are photo-electric devices of the emissive type, as distinct from the barrier-layer and photo-conductive cells. They may be divided into two classes:

(1) high-vacuum phototubes;

(2) gas-filled phototubes.

Each of these groups can be subdivided into red-sensitive and blue-sensitive phototubes, the spectral response depending upon the cathode material.

THE CATHODE

The cathode of a phototube is made of a material with a low work function. In fact, this work function is so low that, when the cathode is struck by a beam of light, free electrons are emitted. It is known that in this respect caesium is sensitive to red and infra-red rays, whereas for instance potassium is sensitive to the electro-magnetic waves of shorter wavelength, i.e. blue, violet and ultra-violet.

In the course of development of photo-emissive cathodes it proved that very good red-sensitive cathodes could be made with caesium on a layer of oxidized silver, this being called the "C" type of cathode. A very good blue-sensitive cathode is made of caesium on antimony and is called the "A"

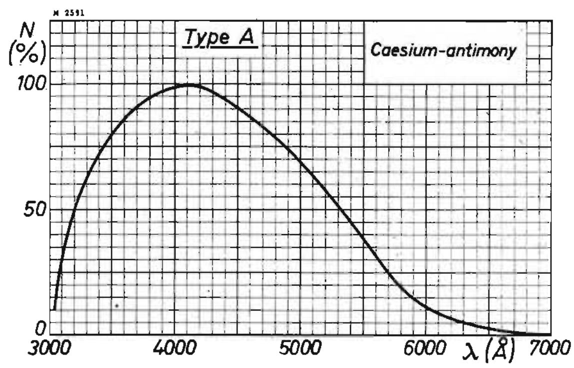


Fig.1. Spectral response curve of an "A" type of cathode.

In Fig.1 the spectral response curve is shown of the "A" type of cathode of a phototube. It is seen that the greatest sensitivity lies in the region between wavelengths of 3700 Å and 4500 Å, thus in the range of violet and blue light. Ultra-violet rays, having a wavelength below 3850 Å, are absorbed by the glass envelope of the tube. As for the phototube, the curve is therefore only valid above 3850 Å. If phototubes sensitive to ultra-violet rays are desired, the bulb must be provided with a quartz window, to let these rays pass on to the cathode.

Fig.2 shows the spectral response curve for the "C" type of cathode. Maximum sensitivity lies between 7 000 Å and 9 000 Å, which is the region of red and infra-red light.

The photo-cathode can be applied on a silver plate, in which case the entire bulb is transparent (for instance the phototube 90 CV). In other cases the cathode is applied to the inner side of the glass envelope, the bulb then being only partly transparent; the space where the beam of light enters the phototube is then called the window.

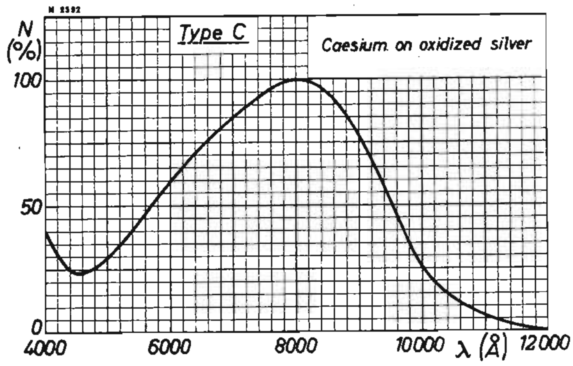


Fig.2. Spectral response curve of a phototube with "C" type of cathode.

A value for the maximum permissible cathode current is given in the tube data. This value holds when the entire cathode surface is illuminated uniformly. If, however, only part of the cathode surface is illuminated, the cathode current must be kept correspondingly lower.

DARK CURRENT

Even if a photo-cathode is not illuminated it will emit some electrons, if only as a result of the ambient temperature. The work function of the cathode surface is so low that even at room temperature some thermionic emission can be observed. The current resulting from this thermionic emission is called the dark current and is rather low. For the gas-filled tubes a dark current of less than 10^{-7} A can be guaranteed at 100 V, whilst for the vacuum tubes even less than $5 \cdot 10^{-8}$ A can be guaranteed.

SENSITIVITY

The sensitivity of a phototube depends on the type of cathode used and is expressed in μA/lm. It must be noted that this value has no significance if the spectral energy distribution of the light source is not known.

Especially for phototubes sensitive to the invisible infra-red radiation, the sensitivity depends largely on the spectral composition of the light. The eye cannot distinguish between a large and a small component of infra-red radiation. If there are two sources of light radiating an equal number of lumens, it is possible that one radiates far more of the invisible infra-red than the other. The sensitivity of a "C" cathode will be much greater for the former light source than for the latter. For instance, the sensitivity of a phototube with a "C" type cathode is, for incandescent light with a colour temperature of 2700 °K, 20 μA/lm, but for daylight, which usually has a much smaller infra-red component, the sensitivity is only 4 μA/lm. The daylight sensitivity of a phototube with an "A" type cathode, however, is about 80 μA/lm, whilst for a lamp with a colour temperature of 2700 °K it is 45 μA/lm.

Since phototubes are normally employed in combination with incandescent lamps, the sensitivity of phototubes is measured with a lamp with tungsten filament operating at a colour temperature of 2700 °K

THE ANODE

The anode may consist of a single rod or a bent wire, the so-called hair pin anode. Where the total electronic current is only very small (5 10 μA), there is no need of a large anode surface for cooling. The anode, having to be placed between the light source and the cathode, is made small and thin, so that only a very small part of the light beam is intercepted.

CHARACTERISTICS OF HIGH VACUUM PHOTOTUBES

In Fig.3 the saturation characteristic of a high-vacuum phototube is represented The anode current depends on the quantity of light falling on the cathode, so that the sensitivity is indicated in μA/lm. It is seen that only the lower anode voltages effect the anode current, this being due to the fact that not all emitted electrons are drawn towards the anode. Above a certain value the anode current is practically independent of the anode voltage. When all freed electrons impinge upon the anode, saturation is reached The voltage where the curve becomes flat is called the saturation voltage.

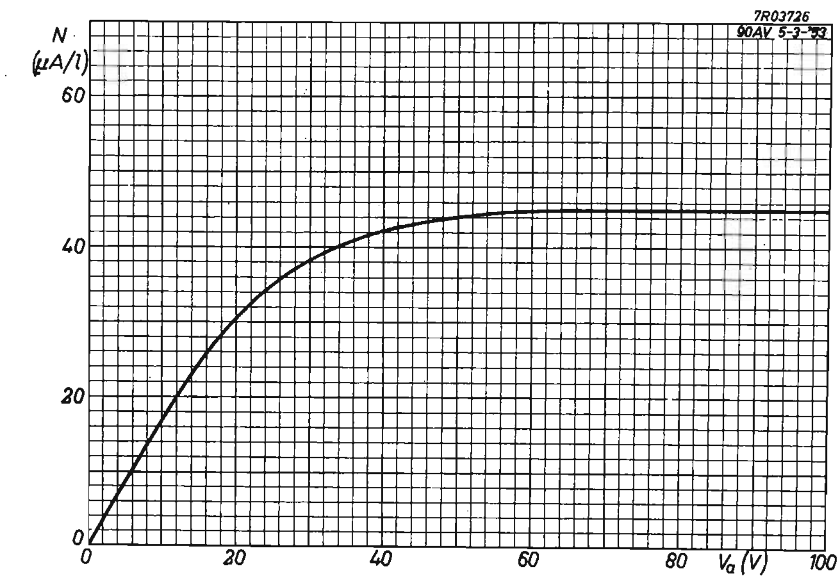


Fig.3. Saturation characteristic of a high-vacuum phototube.

If high-vacuum tubes are operated under the conditions recommended, their characteristics remain substantially constant over long periods of time.

TYPES OF HIGH-VACUUM PHOTOTUBES

The high-vacuum phototubes dealt with in this documentation are:

58 CV .... red-sensitive
90 AV .... blue-sensitive
90 CV .... red-sensitive
3545 .... red-sensitive

TOLERANCES

The values given for sensitivity in the data are the initial values for average phototubes. The ratio of the maximum to the minimum initial sensitivity of phototubes of a given type will not exceed 3 to 1. These values are given below.

Type	Sensitivity in µA/lm at				
	0 hours			500 hours	V_a
	min.	nom.	max.	min.	volts
58CV	11	20	33	6	50
90AV	35	45	105	20	85
90CV	13	20	40	6	50
3545	18	25	54	10	90
58CG	60	85	180	30	85
90AG	75	130	225	40	85
90CG	72	125	216	35	85
3546	95	150	285	50	85
3554	95	150	285	50	85

STABILITY OVER LIFE

Where a phototube is continuously operated under average conditions (with continuous light falling on the phototubes) its sensitivity may fall after 500 hours by as much as about 50% of the minimum sensitivity at 0 hours, as can be seen in the above table.

The sensitivity of phototubes when run intermittently will be wholly or partially restored during the inoperative periods.

AMBIENT TEMPERATURE

(a) RED SENSITIVE TYPES

When using these phototubes at temperatures above 50 °C, up to max. 100 °C, no deterioration of the photocathode sensitivity will result.

Between 30 and 100 °C the dark current will increase about linearly up to max. 2.5 µA in gasfilled types and up to max. 1.5 µA in vacuum types of phototube.

(b) BLUE SENSITIVE TYPES

When using these phototubes at temperatures between 50 and 100 °C, a decrease of about 20% of the sensitivity of the photocathode will result.

Between 50 and 100 °C the dark current will increase about linearly up to max. 1 µA in both gasfilled and vacuum types of phototube.

However, for the phototubes 90AG and 90AV a maximum ambient temperature of 70 °C can be allowed.

Phototube 58 CV

The phototube 58 CV is of the vacuum type and is provided with a caesium-on-oxidized-silver cathode. It is most sensitive to incandescent light sources and to near infra-red radiation.

This phototube is designed for end-on incidence of illumination and its small dimensions make it suitable for applications where space is a limiting factor, or where it is desired to have multiple banks of phototubes in operation.

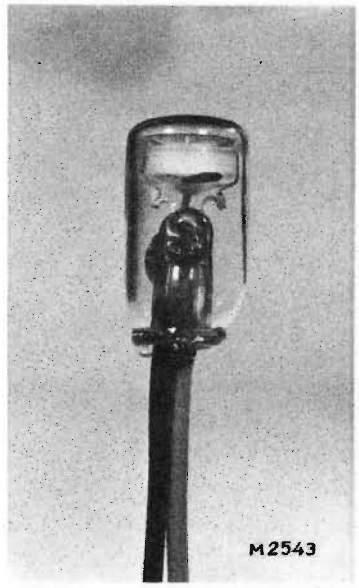


Fig.4. Phototube 58 CV.

CATHODE

Surface	caesium-on-oxidized-silver
Projected sensitive area	1.1 cm^2 (0.171 sq.in)

MOUNTING POSITION any

CAPACITANCE

between anode and cathode 3.0 pF

CHARACTERISTICS

Dark current (V_a = 50 V, t_{amb} = 50 °C)	max.	0.05 μA
Dark current (V_a = 50 V, t_{amb} = 100 °C)	max.	1.5 μA
Sensitivity (V_a = 50 V)	=	20 μA/lm*)

TYPICAL OPERATING CONDITIONS

Anode supply voltage.	50 V
Anode resistor.	1 MΩ

LIMITING VALUES (design centre values)

Anode supply voltage.	max.	250 V
Cathode current density	max.	30 mμA
Ambient temperature	max.	100 °C

ELECTRODE ARRANGEMENT, CONNECTIONS AND DIMENSIONS (in mm)

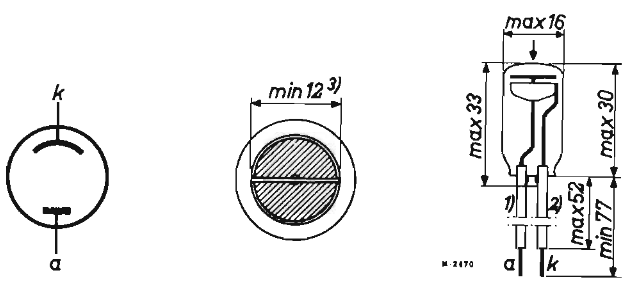


Fig.5. Dimensions in mm and electrode connections.

1) Red lead; 2) black lead; 3) sensitive cathode area.

The arrow shows the direction of the incident radiation.

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*) Measured with a lamp of colour temperature 2700 °K.

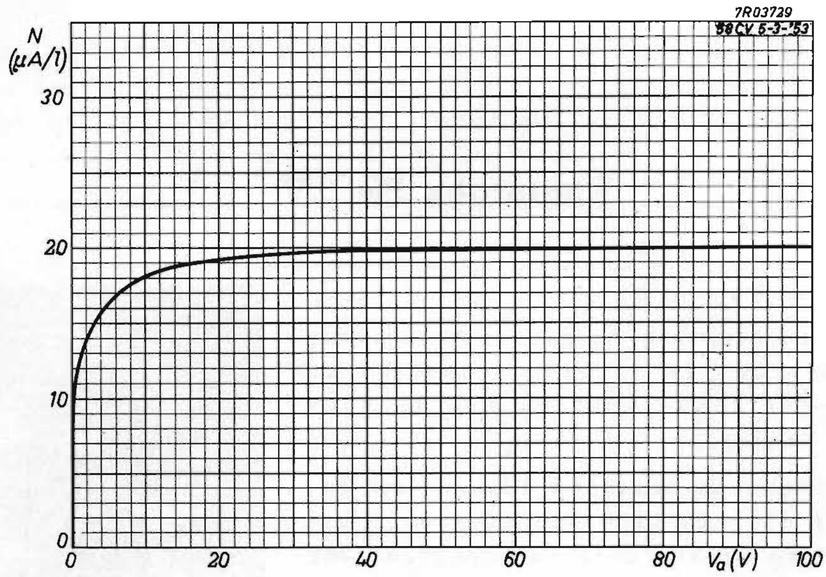


Fig.6. Saturation characteristic.

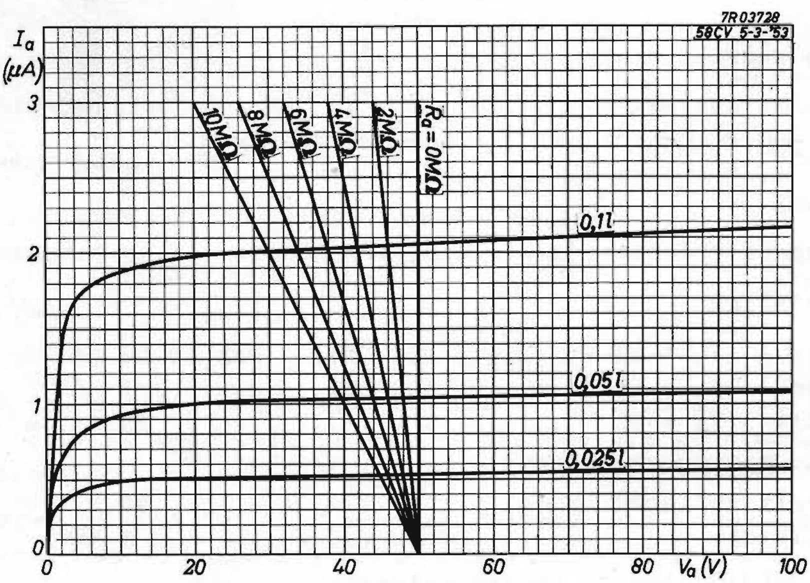


Fig.7. I_a/V_a characteristics.

Phototube 90 AV

The phototube 90 AV is of the vacuum type with a caesium-on-antimony cathode. It is most sensitive to daylight and light radiation having a blue predominance. It has negligible response to infra-red radiation.

The use of the miniature all-glass technique permits of a rigid construction and a maximum exposed cathode area for a phototube of these small dimensions.

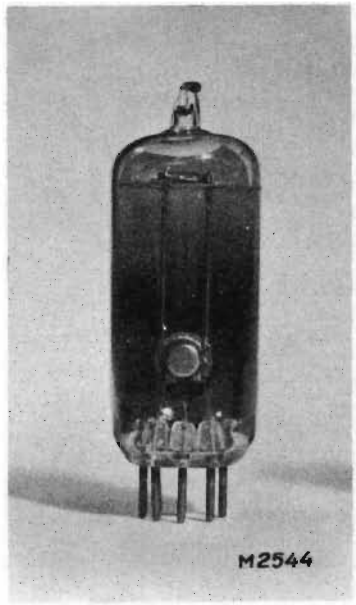


Fig.8. Phototube 90 AV.

CATHODE

Surface	caesium-on-antimony
Projected sensitive area	4 cm^2 (0.620 sq.in)

MOUNTING POSITION	any

CAPACITANCE

between anode and cathode	0.7 pF

CHARACTERISTICS

Dark current (V_a = 85 V)	max.	0.05 µA
Sensitivity (V_a = 85 V)	=	45 µA/lm *)

TYPICAL OPERATING CONDITIONS

Anode supply voltage.	85 V
Anode resistor.	1 MΩ

LIMITING VALUES (design centre values)

Anode supply voltage.	max.	100 V
Cathode current density	max.	12.5 mµA/mm^2
Ambient temperature	max.	70 °C

ELECTRODE ARRANGEMENT, CONNECTIONS AND DIMENSIONS (in mm)

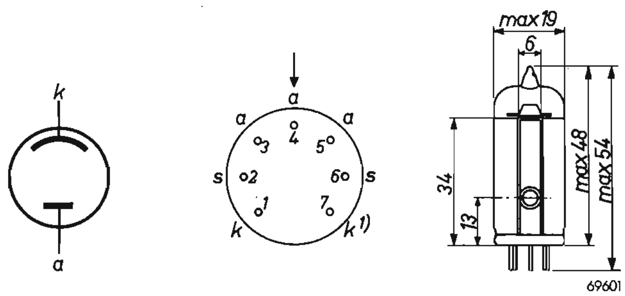


Fig.9. Dimensions in mm and electrode connections.
1) Pins 1,2,6 and 7 as well as pins 3,4 and 5 should be interconnected. The arrow shows the direction of the incident radiation.

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*) Measured with a lamp of colour temperature 2700 °K.

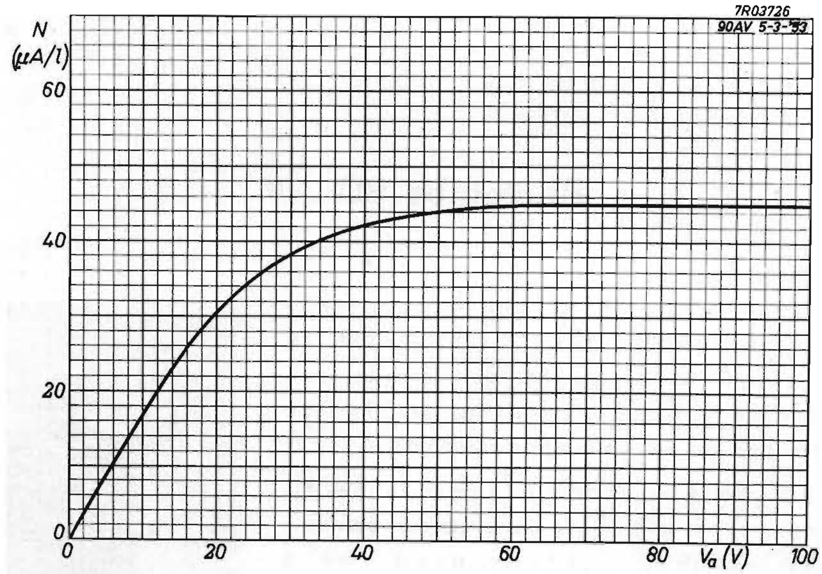


Fig.10. Saturation characteristic.

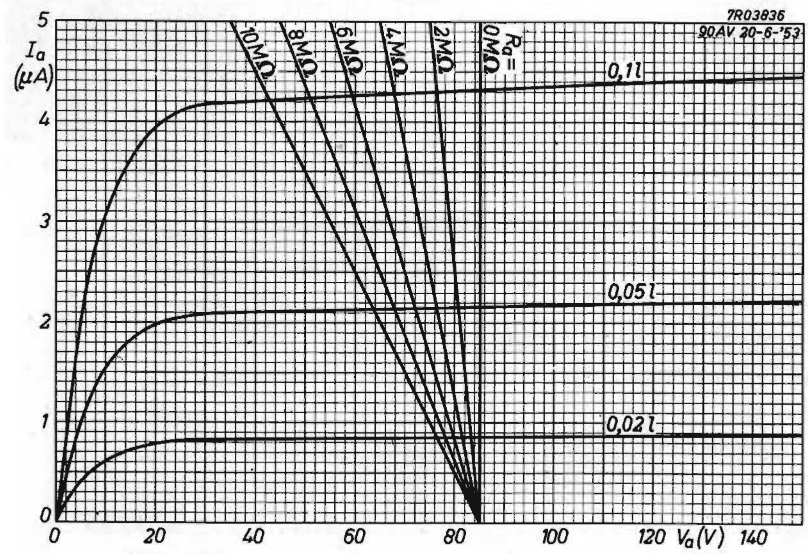


Fig.11. I_a/V_a characteristics.

Phototube 90 CV

The phototube 90 CV is a vacuum tube with a caesium-on-oxidized-silver cathode, thus most sensitive to incandescent light sources and to near infra-red radiation. The use of the miniature all-glass base permits of a rigid construction and a maximum exposed cathode area for a phototube of this size.

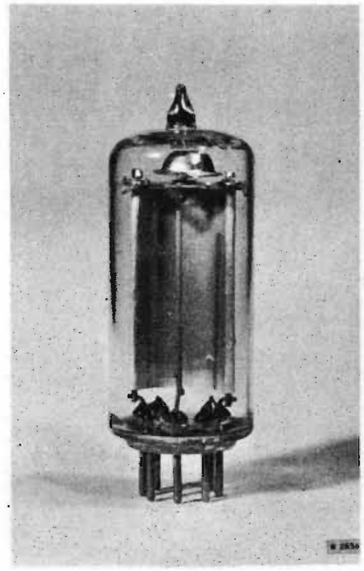


Fig.12. Phototube 90 CV.

CATHODE

Surface	caesium-on-oxidized silver
Projected sensitive aerea	2.4 cm^2 (0.372 sq. in)

MOUNTING POSITION — any

CAPACITANCE

between anode and cathode — 0.6 pF

CHARACTERISTICS

Dark current (V_a = 50 V, t_{amb} = 50 °C)	max.	0.05 μA
Dark current (V_a = 50 V, t_{amb} = 100 °C)	max.	1.5 μA
Sensitivity (V_a = 50 V)	=	20 μA/lm *)

TYPICAL OPERATING CONDITIONS

Anode supply voltage.	50 V
Anode resistor.	1 MΩ

LIMITING VALUES (design centre values)

Anode supply voltage.	max.	250 V
Cathode current density	max.	0.03 μA/mm^2
Ambient temperature	max.	100 °C

ELECTRODE ARRANGEMENT, CONNECTIONS AND DIMENSIONS (in mm)

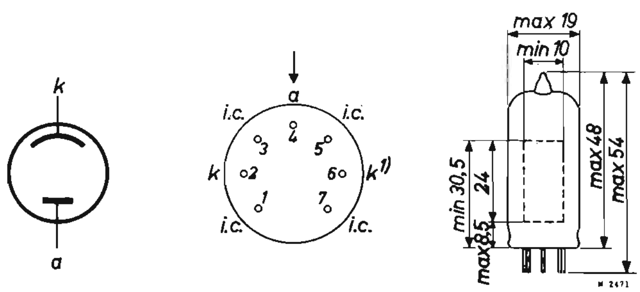


Fig.13. Dimensions in mm and electrode connections.

1) Pins 1,2,6 and 7 as well as pins 3,4 and 5 should be interconnected. The arrow shows the direction of the incident radiation.

*) Measured with a lamp of colour temperature 2700 °K.

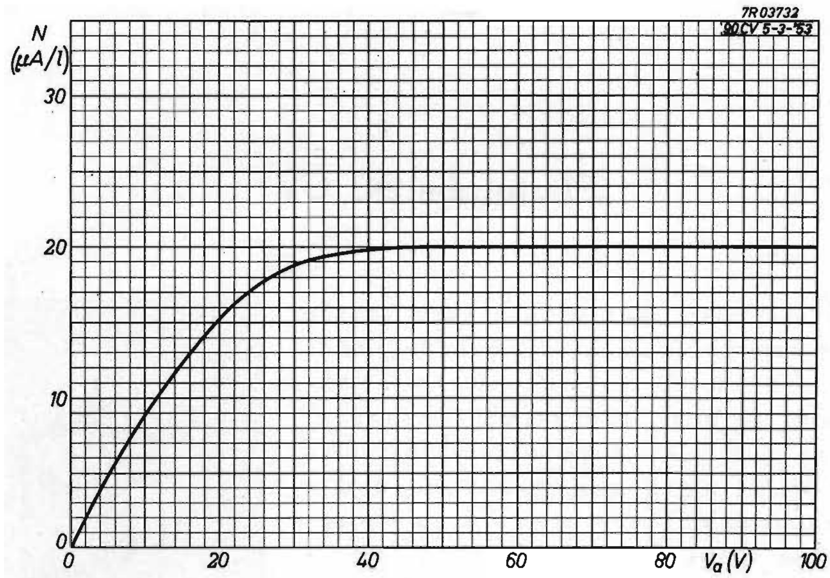


Fig.14. Saturation characteristic.

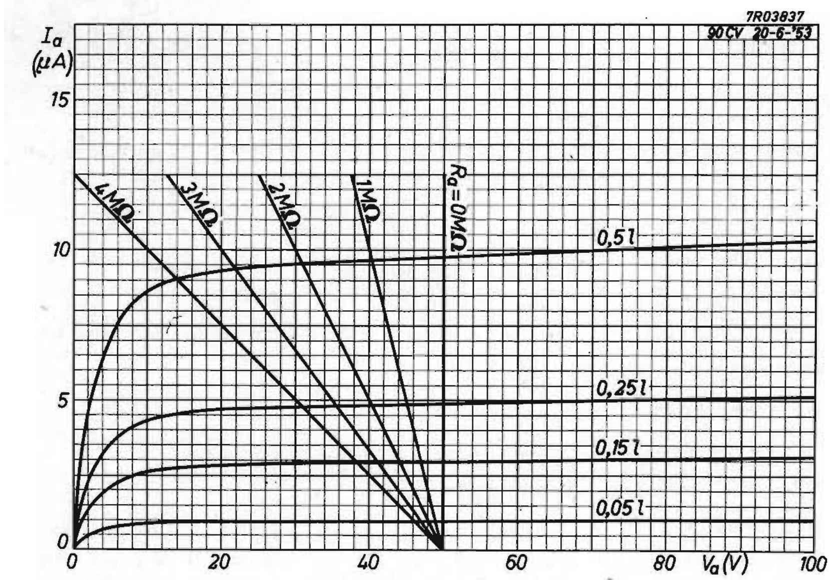


Fig.15. I_a/V_a characteristics.

Phototube 3545

The phototube 3545 is of the vacuum type with a caesium-on-oxidized-silver cathode, most sensitive to incandescent light sources and to near infra-red radiation.

In order to prevent microphony if the tube is used in equipment which is subjected to vibration, special measures have been taken to obtain a rigid electrode structure. The top ends of anode and cathode, for example, are interconnected mechanically via a glass bead to prevent vibration of these electrodes as a result of impact excitation.

The 3545 can be supplied with a standard PeeWee or with a two-pin base.

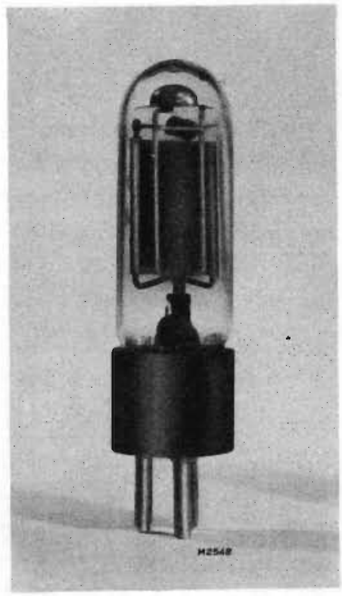


Fig.16. Phototube 3545(PW)

CATHODE

Surface	caesium-on-oxidized-silver
Projected sensitive area	0.9 cm^2 (0.140 sq. in)

MOUNTING POSITION any

CAPACITANCE

between anode and cathode 2 pF

CHARACTERISTICS

Dark current (V_a = 90 V, t_{amb} = 50 °C)	max.	0.05 μA
Dark current (V_a = 90 V, t_{amb} = 100 °C)	max.	1.5 μA
Sensitivity (V_a = 90 V)	=	25 μA/lm [1]

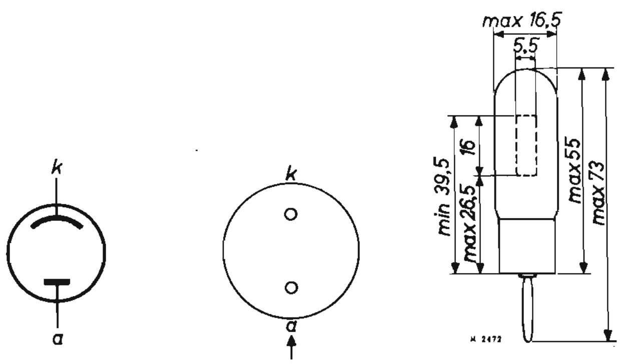
TYPICAL OPERATING CONDITIONS

Anode supply voltage.	90 V
Anode resistor.	1 MΩ

LIMITING VALUES (design centre values)

Anode supply voltage.	max.	250 V
Cathode current density	max.	50 mμA/mm^2
Ambient temperature	max.	100 °C

ELECTRODE ARRANGEMENT, CONNECTIONS AND DIMENSIONS (in mm)



[1]) Measured with a lamp of colour temperature 2700 °K.

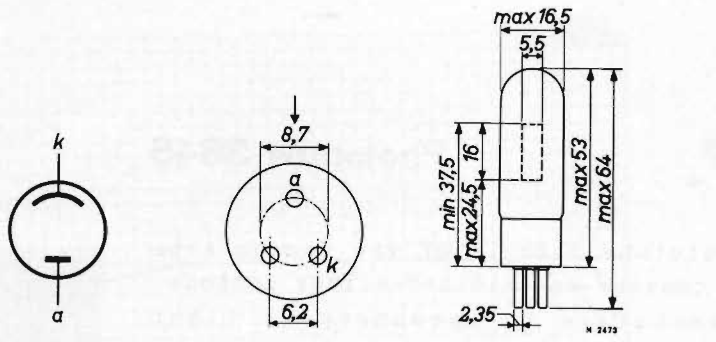


Fig.17. Dimensions in mm and electrode connections: the second figure shows the PW-base. The arrow shows the direction of the incident radiation.

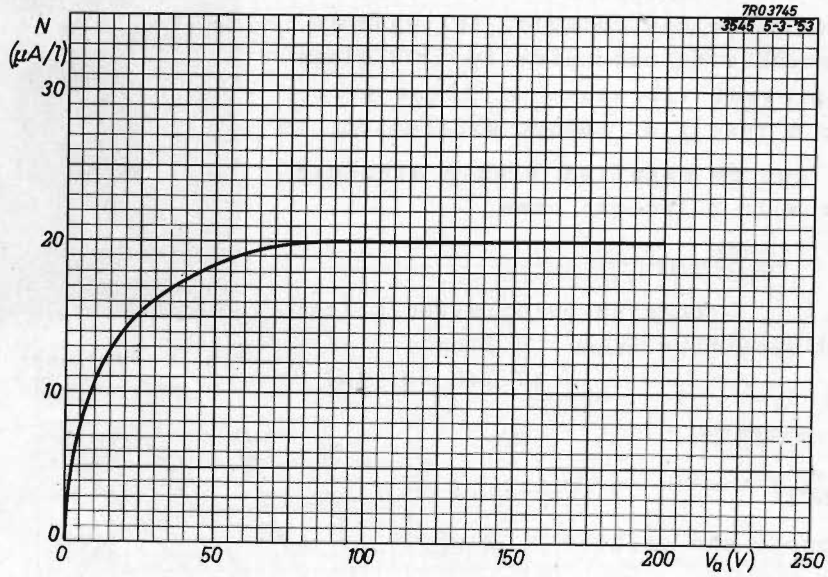


Fig.18. Saturation characteristic.

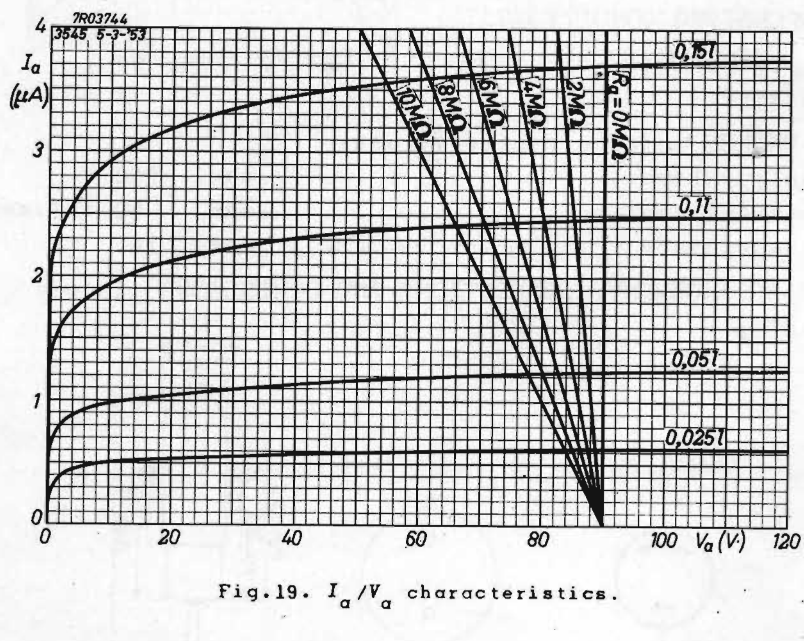


Fig.19. I_a/V_a characteristics.

GAS-FILLED PHOTOTUBES

In the course of the last twenty years the sensitivity of particularly the blue-sensitive high-vacuum phototubes has been improved quite remarkably. This is illustrated by comparing the old blue-sensitive tube type 3510, having a sensitivity of 3 μA/lm, with the newer type 90AV which has a sensitivity of 45 μA/lm. Red-sensitive tubes have not been improved to the same extent.

For several purposes a much greater sensitivity is required and this can be reached in a rather simple way by letting a small quantity of inert gas into the bulb.

The gas amplification can be explained as follows: When the electrons pass from the cathode to the anode in a gas-filled tube, on their way they will meet the gas atoms. If the velocity of the electrons is only small, this will be of no influence on the photo current. If, on the other hand, an electron traverses a potential which exceeds the ionization voltage of the inert gas concerned, it has a velocity sufficiently high to ionize gas atoms by collision. Through this collision a positive ion is formed, which travels to the cathode, and a free electron is released, which, together with the original electron, passes to the anode. These two electrons may cause the ionization of other gas atoms so that for one electron released from the cathode by the beam of light, several electrons may arrive at the anode. The positive ions resulting from the ionization impinge on the cathode and may release other electrons from its surface, which, on their way to the anode, ionize other gas atoms, and so on. It will be clear

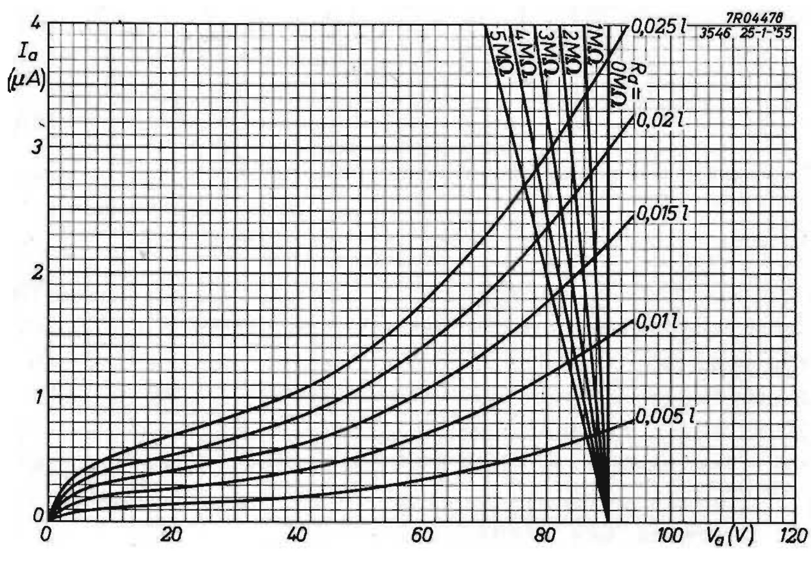


Fig.20. I_a/V_a characteristics of a gas-filled phototube.

that in this way the photo-current can be amplified several times, and this amplification increases with the anode voltage, since the velocity of the electrons is higher as the potential difference traversed is larger. The number of collisions resulting in ionization therefore increases with the anode voltage.

The anode voltage however, may not be increased indefinitely because at too high an anode voltage a glow discharge would occur which may damage the tube. To limit the effect of accidental over-running a protective resistor of at least 0.1 MΩ should be inserted. The ignition voltage of gas-filled phototubes is about 100 to 150 V for the different types and the anode voltage has to be made much lower; for instance, 75 to 100 V. The gas amplification that can be obtained in this way ranges between 5 and 10 times.

Typical I_a/V_a characteristics of a gas-filled phototube are shown in Fig.20. In the curved parts of the characteristics the voltage across the load resistor will not be exactly proportional to the amount of light falling on the cathode. For this reason gas-filled phototubes are not very suitable for exact measurement purposes; they are, however, excellent for sound reproduction, because at the usual value of the load resistor in sound-film apparatus, the bend in the characteristic is of negligible influence.

For industrial purposes, where a great sensitivity prevails over exactness, the gas-filled phototube is very useful.

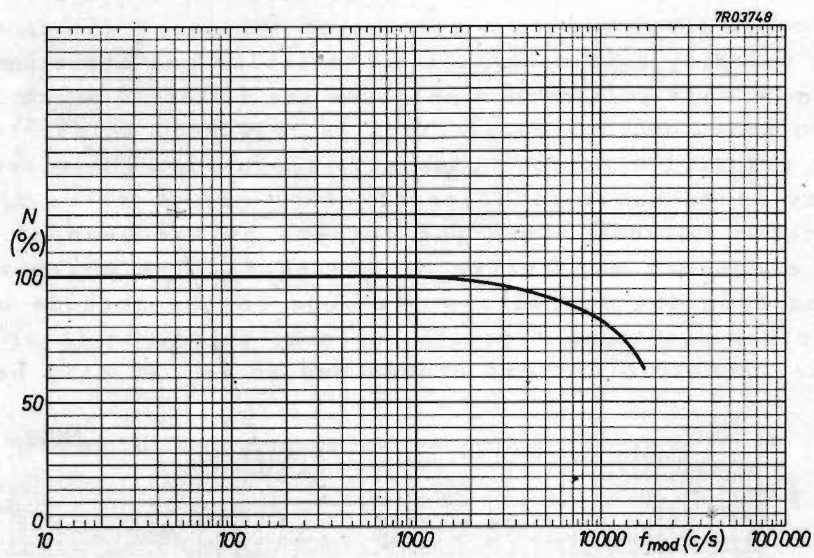


Fig.21. Frequency characteristic of a gas-filled phototube.

The gas amplification decreases at higher frequencies. This is due to the fact that the ions formed in the gas are much heavier than the electrons, so that their velocity is relatively low. When the light is suddenly interrupted there are still some ions moving to the cathode which release some electrons, ionizing other gas atoms, and so on. The number of newly formed ions, however, is too small to keep the anode current flowing and so the latter is gradually decreasing. Likewise the anode current will not reach its final value immediately after the cathode is illuminated.

Thus at higher frequencies the gas amplification is not able to follow the fluctuations of the light, and the result is that above

1000 c/s the amplification decreases, but up to 10.000 c/s this decrease is so small as to be of no influence for practical applications. A typical example of a frequency characteristic of a gas-filled phototube is given in Fig.21.

The types of gas-filled phototubes dealt with in this documentation are:

58 CG .... red sensitive
90 AG .... blue-sensitive
90 CG .... red-sensitive
3546 .... red-sensitive
3554 .... red-sensitive

Phototube 58 CG

The phototube 58 CG of the gas-filled type, with a ceasium-on-oxidized-silver cathode, thus most sensitive to incandescent light sources and to near infrared radiation.

This tube is designed for end-on incidence of illumination and its small dimensions render it suitable for applications where space is a limiting factor or where it is desired to have multiple banks of phototubes in operation.

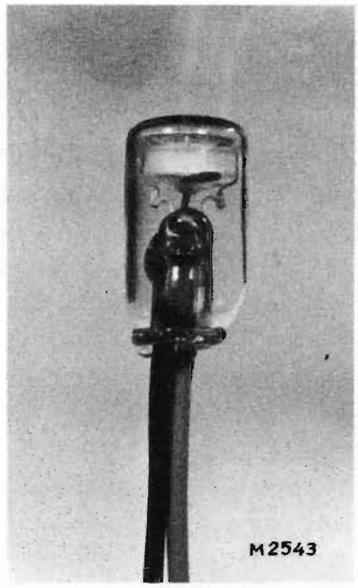


Fig.22. Phototube 58 CG.

CATHODE

Surface	caesium-on-oxidized-silver
Projected sensitive area	1.1 cm^2 (0.171 sq. in)

MOUNTING POSITION any

CAPACITANCE

between anode and cathode 3.0 pF

CHARACTERISTICS

Dark current (V_a = 85 V, t_{amb} = 50 °C)	max.	0.1 μA
Dark current (V_a = 85 V, t_{amb} = 100 °C)	max.	2.5 μA
Sensitivity (V_a = 85 V)	=	108 μA/lm*)

TYPICAL OPERATING CONDITIONS

Anode supply voltage.	85 V
Anode resistor.	1 MΩ

LIMITING VALUES (design centre values)

Anode supply voltage.	max.	90 V
Cathode current density	max.	15 mμA/mm^2
Ambient temperature	max.	100 °C

ELECTRODE ARRANGEMENT, CONNECTIONS AND DIMENSIONS (in mm)

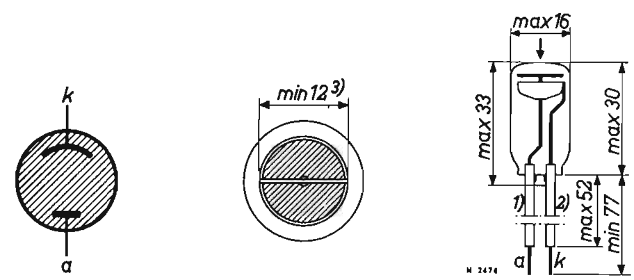


Fig.23. Dimensions in mm and electrode connections.

1) Red lead; 2) black lead; 3) sensitive cathode area.

The arrow shows the direction of the incident radiation.

*) Measured with a lamp of colour temperature 2700 °K.

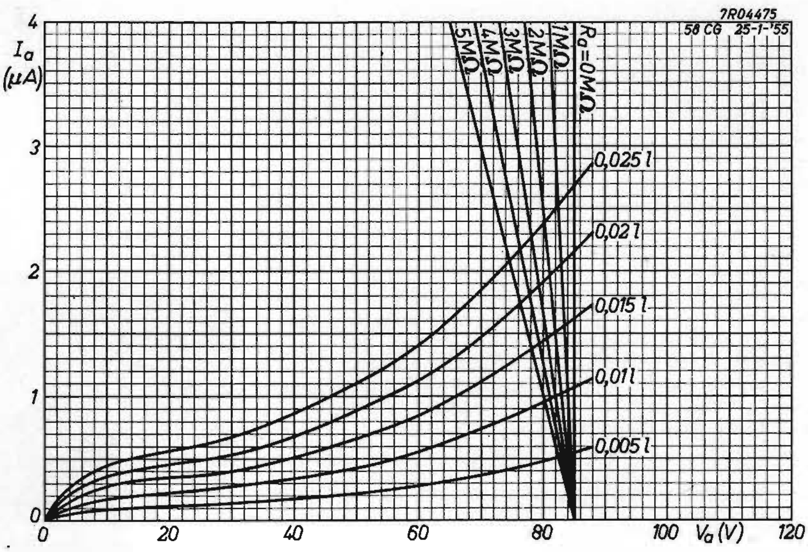


Fig. 24. I_a/V_a characteristics.

Remark: The tube 58CG is also available with PW base (58CG.PW).

Phototube 90 AG

The phototube 90 AG is of the gas-filled type with a caesium-on-antimony cathode. It has a high sensitivity to daylight and to light sources predominating in blue radiation. Its response to infra-red radiation is negligible. The use of the miniature all-glass technique permits of a rigid construction and a very large sensitivity surface for a phototube of such small dimensions.



Fig. 25. Phototube 90 AG.

CATHODE

Surface	caesium-on-antimony
Projected sensitive area	4 cm^2 (0.620 sq. in)

MOUNTING POSITION any

CAPACITANCE

Between anode and cathode 0.7 pF

CHARACTERISTICS

Dark current (V_a = 85 V) . . . . .max.	0.1 μA
Sensitivity (V_a = 85 V) . . . . =	130 μA/lm*)

TYPICAL OPERATING CONDITIONS

Anode supply voltage.	85 V
Anode resistor.	1 MΩ

LIMITING VALUES (design centre values)

Anode supply voltage. . . . . .max.	90 V
Cathode current density . . . . .max.	6 mμA/mm^2
Ambient temperature . . . . .max.	70 °C

ELECTRODE ARRANGEMENT, CONNECTIONS AND DIMENSIONS (in mm)

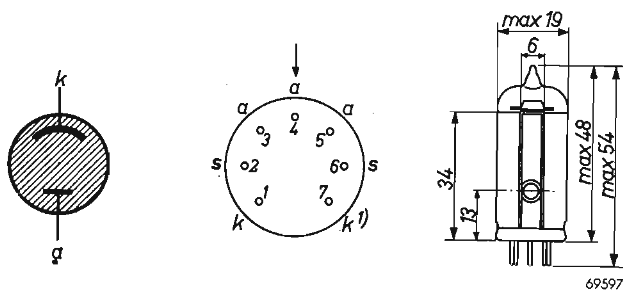


Fig. 26. Dimensions in mm and electrode connections.
1) Pins 1, 2, 6 and 7 as well as pins 3, 4 and 5 should be interconnected. The arrow shows the direction of the incident radiation.

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*) Measured with a lamp of colour temperature 2700 °K.

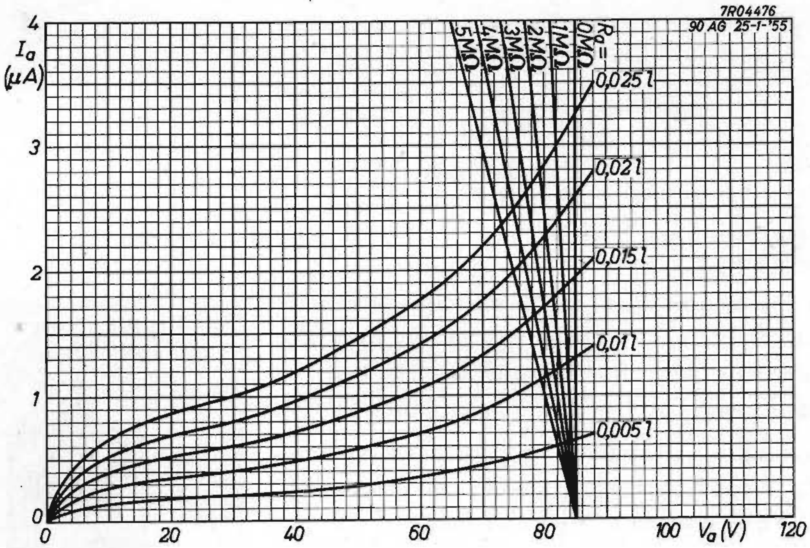


Fig.27. I_a/V_a characteristics.

Phototube 90 CG

The 90 CG is a gas-filled phototube with a caesium-on-oxidized-silver cathode, so it is most sensitive to incandescent light sources and near infra-red radiation.

The use of the miniature all-glass technique permits of a rigid construction and a very large sensitive surface for a phototube of this size.

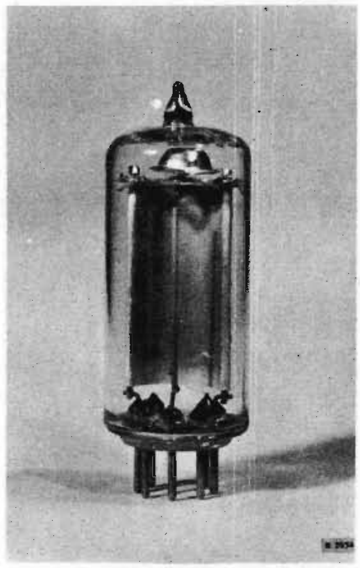


Fig. 28. Phototube 90 CG.

CATHODE

Surface	caesium-on-oxidized-silver
Projected sensitive area	2.4 cm^2 (0.372 sq. in)

MOUNTING POSITION any

CAPACITANCE

between anode and cathode 0.6 pF

CHARACTERISTICS

Dark current (V_a = 85 V, t_{amb} = 50 °C)	max.	0.1 μA
Dark current (V_a = 85 V, t_{amb} = 100 °C)	max.	2.5 μA
Sensitivity (V_a = 85 V)	=	125 μA/lm *)

TYPICAL OPERATING CONDITIONS

Anode supply voltage	85 V
Anode resistor	1 MΩ

LIMITING VALUES (design centre values)

Anode supply voltage	max.	90 V
Cathode current density	max.	7 mμA/mm^2
Ambient temperature	max.	100 °C

ELECTRODE ARRANGEMENT, CONNECTIONS AND DIMENSIONS (in mm)

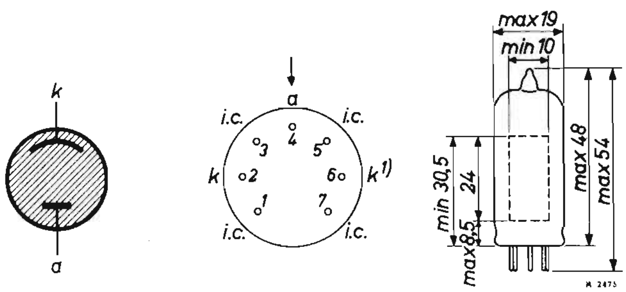


Fig. 29. Dimensions in mm and electrode connections. Pins 1, 2, 6 and 7 as well as pins 3, 4 and 5 should be interconnected. The arrow shows the direction of the incident radiation.

*) Measured with a lamp of colour temperature 2700 °K.

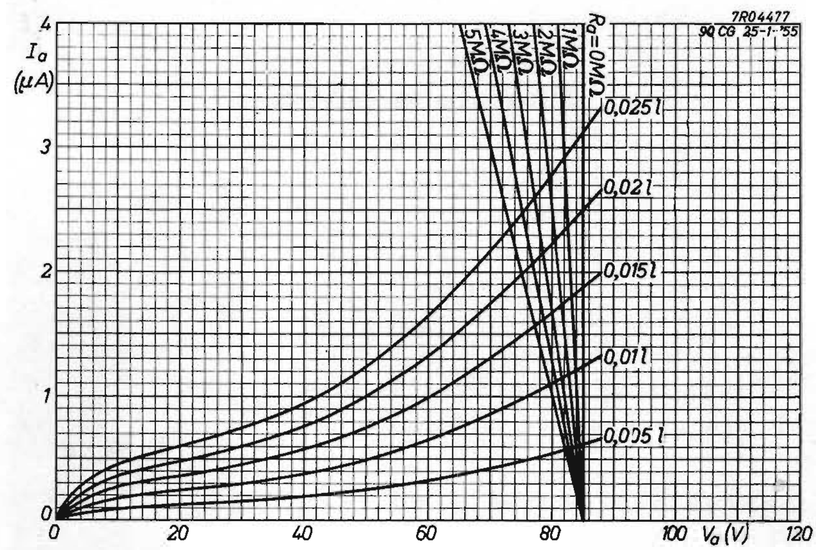


Fig.30. I_a/V_a characteristics.

Phototube 3546

The phototube 3546 is of the gas-filled type with a caesium-on-oxidized-silver cathode, thus most sensitive for incandescent light sources and near infra-red radiation. The small dimensions make it very useful in standard sound-film projectors and in such light-operated relays where small dimensions are of paramount importance.

In the construction of the electrode system great care has been taken to avoid occurrence of microphony. the top ends of the anode and the cathode are connected to each other by means of a glass bead so that the tube is quite insensitive to vibration of the apparatus in which it is mounted.

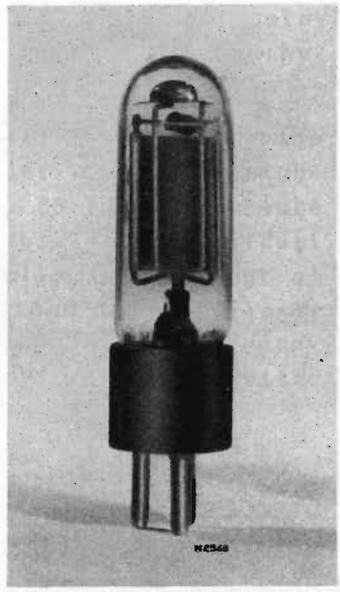


Fig.31. Phototube 3546(PW).

CATHODE

Surface	caesium-on-oxidized-silver
Projected sensitive area	0.9 cm^2 (0.140 sq. in)

MOUNTING POSITION any

CAPACITANCE

between anode and cathode 2 pF

CHARACTERISTICS

Dark current (V_a = 90 V, t_{amb} = 50 °C)	max.	0.1 μA
Dark current (V_a = 90 V, t_{amb} = 100 °C)	max.	2.5 μA
Sensitivity (V_a = 90 V)	=	150 μA/lm [1]

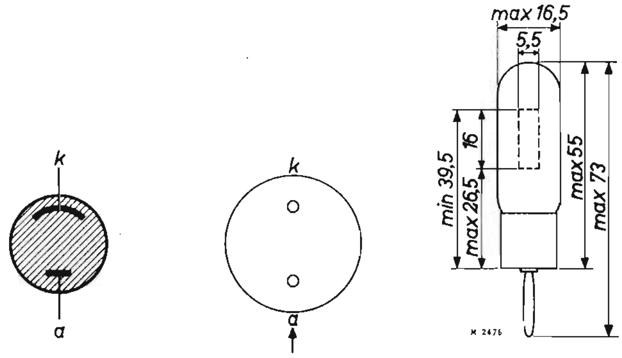
TYPICAL OPERATING CONDITIONS

Anode supply voltage	90 V
Anode resistor	1 MΩ

LIMITING VALUES (design centre values)

Anode supply voltage	max.	90 V
Cathode current density	max.	20 $m\mu A/mm^2$
Ambient temperature	max.	100 °C

ELECTRODE ARRANGEMENT, CONNECTIONS AND DIMENSIONS (in mm)



[1]) Measured with a lamp of colour temperature 2700 °K.

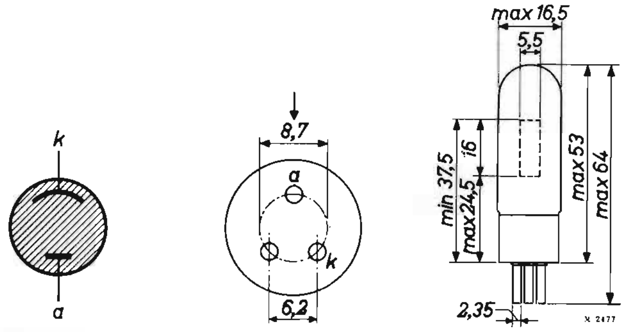


Fig.32. Dimensions in mm and electrode connections; the second figure shows the PW-base: 3546PW.
The arrow shows the direction of the incident radiation.

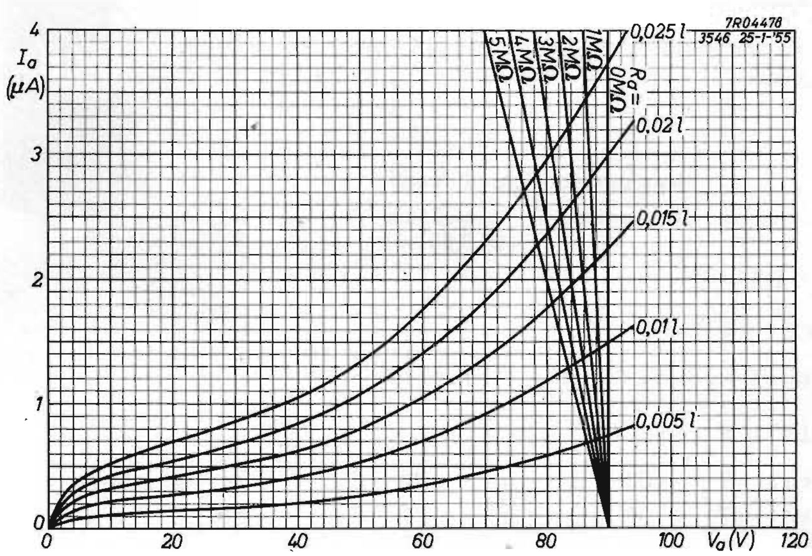


Fig.33. I_a/V_a characteristics.

Phototube 3554

Type 3554 is a gas-filled phototube with a caesium-on oxidized-silver cathode. It has maximum response for incandescent light and near infra-red radiation. Its high sensitivity renders it suitable for use in standard cinema installations and in such light-operated relays where a relatively large cathode surface is wanted.

The tube is equipped with a small tapered four-pin base.

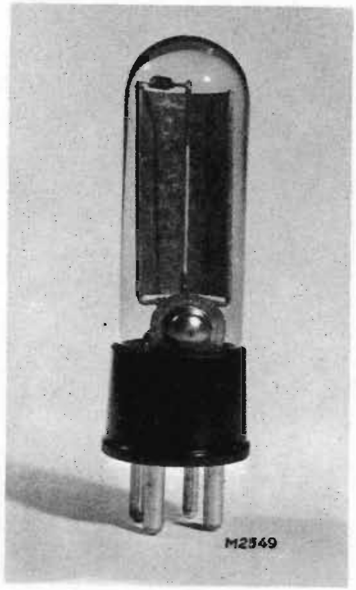


Fig.34. Phototube 3554.

CATHODE

Surface	caesium-on-oxidized-silver
Projected sensitive area	5.2 cm^2 (0.793 sq. in)

MOUNTING POSITION any

CAPACITANCE

between anode and cathode 3.4 pF

CHARACTERISTICS

Dark current (V_a = 90 V, t_{amb} = 50 °C)	max.	0.1 μA
Dark current (V_a = 90 V, t_{amb} = 100 °C)	max.	2.5 μA
Sensitivity (V_a = 90 V)	=	150 μA/lm [1]

TYPICAL OPERATING CONDITIONS

Anode supply voltage.	90 V
Anode resistor.	1 MΩ

LIMITING VALUES (design centre values)

Anode supply voltage.	max.	90 V
Cathode current density	max.	20 mμA/mm^2
Ambient temperature	max.	100 °C

ELECTRODE ARRANGEMENT, CONNECTIONS AND DIMENSIONS (in mm)

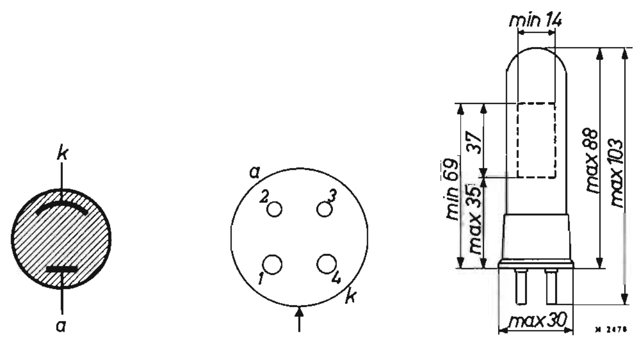


Fig.35. Dimensions in mm and electrode connections.
The arrow shows the direction of the incident radiation.

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[1]) Measured with a lamp of colour temperature 2700 °K.

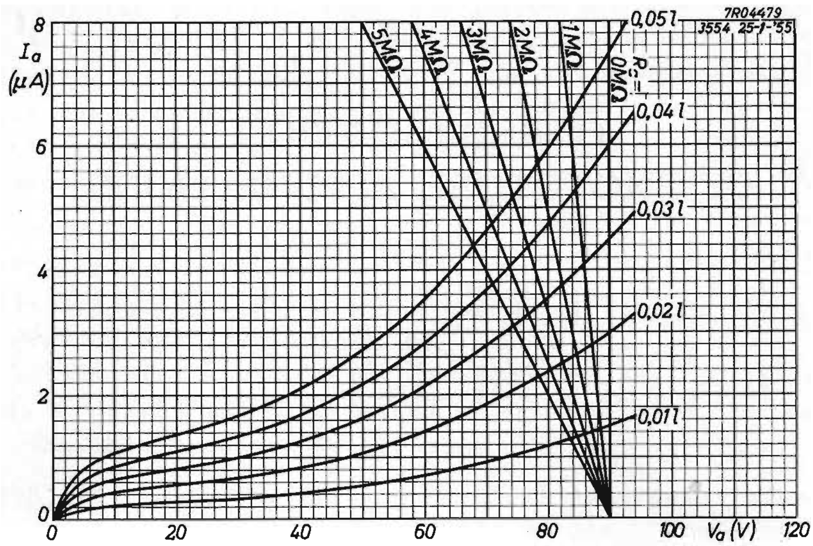


Fig.36. I_a/V_a characteristics.

CLASSIFICATION OF PHOTOTUBE APPLICATIONS

Phototubes are applied for measuring or indicating a quantity or a variation of light or colour. The measurement can be very rough, only indicating whether there is light or not: this may be called on-off action. A more refined measurement is possible when the phototube indicates a certain increase or decrease of light.

Finally, exact quanta of light can be measured. It is not necessary for the light beam to strike the cathode directly; in several cases it will only be possible to use reflected light. Then there is no question of on-off action because every surface, even if it is apparently black, reflects some light, it then being only a matter of a maximum or minimum of reflected light; this may be called contrast action.

Thus the application of phototubes can be divided into two main groups:

(1) with direct light,
(2) with reflected light.

Each group is subdivided into three groups, viz.:

direct light
1. on-off action,
2. action after certain increase or decrease of light,
3. quantitative or spectral measurement of light

and

reflected light
1. contrast action,
2. action after certain amount of increase or decrease of reflected light,
3. quantitative or spectral measurement of reflected light.

Every application of phototubes falls under one of these headings.

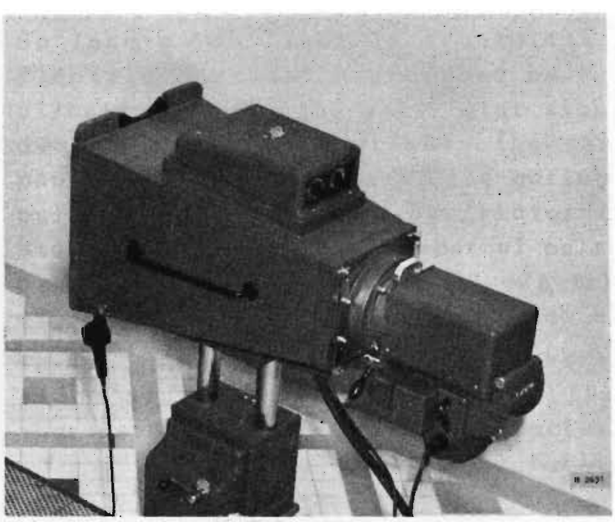


Fig.37. Camera part of X-ray apparatus for medical mass chest examination. The phototube installation measuring the light intensity on the luminescent screen (the photo timer) is mounted in the hood.

The information obtained from the phototube can be utilized in several ways. For on-off and contrast action the usual method is as follows: After due amplification the information of the phototube commands a relay. The relay can either activate some signalling system or it can switch on some auxiliary or servo-mechanism to control a machine.

When a gradually varying phenomenon of light is "observed" by a phototube and a predetermined limit is reached, the tube can bring about the same action as in the case mentioned before. Finally, the amount of light can be measured, and the results can either be registered directly or communicated to other electronic apparatus and to servo-mechanisms. A practical example of the last method is the use of phototubes for automatic exposure control in X-ray film cameras such as are used for medical mass examination in the Army, big factories and for examining the entire population of a district. Owing to the phototube apparatus incorporated in the cameras, the examination can be carried out at a rate of 500 persons per hour. Fig.37 shows a photograph of such a camera, with the photo-timer mounted in the hood. On page 32 a schematic survey is given of various applications of phototubes, grouped according to the classification mentioned above, followed by a list of explanations in alphabetical order.

SURVEY OF PHOTOTUBE APPLICATIONS

- Application of phototubes
  - Direct light
    - On-off action
      - Excitation of relays
        - Alarm
        - Air doffer
        - Counting
        - Flame control
        - Filling
        - Folding
        - Inspection
        - Level control
        - Pin hole detector
        - Safeguard
        - Switching
        - Weighing
      - Excitation of transductors
        - Switching of heavy currents
        - Temperature control
      - Excitation of gas-discharge lamps
        - Calibration of gas and water meters
    - Gradual increase or decrease
      - Excitation of relays at predetermined level
        - Automatic light switching
        - Density control
        - Fire alarm
        - Mercury vapour detectors
        - Smoke detectors
      - Reproduction
        - Image
        - Sound
      - Measuring
        - Absorption meters
        - Astronomy
        - Dust detection
        - Exposure control (X-ray)
        - Meteorology (cloud density)
        - Optical pyrometers
        - Photographic density
        - Saturation of a solution
    - Spectral response
      - Excitation of relays at predetermined level or colour
        - Chlorinization of water
        - Control over mixture of solution
        - Colour inspection during rough tempering
        - Discolouring during chemical reactions
        - Gas detector
      - Measuring
        - Colorimeters
        - Flame photometers
        - Spectral analysis
  - Reflected light
    - Contrast action
      - Excitation of relays
        - Examination for:
          - double printing
          - cracks
          - leaks
          - insulation
          - seams
        - Register control
      - Excitation of transductors
        - Register control
        - Switching of heavy currents
    - Gradual increase or decrease
      - Excitation of relays at certain level
        - Baking colour control
        - Grinding machines
        - Polishing machines
        - Spraying machines
      - Reproduction
        - Facsimile
        - Sound
      - Measuring
        - Exposure meters
        - Integrating photometers
    - Spectral response
      - Excitation of relays
        - Final inspection
        - Mixing of paints or ink
        - Sorting to colour
      - Measuring
        - Chemical analysis
        - Colour comparison
        - Spectrometers

ALPHABETICAL LIST OF PHOTOTUBE APPLICATIONS

ABSORPTION METER

Photometer used for measuring the light transmission of liquids and translucent materials for comparison or standardization.

AIR DOFFER

Photo electric air-jet device used in laundries. The laundered articles coming from the ironer on a conveyer intercept a light beam striking a phototube. This operates an air-jet device, which is mounted in such a way that the articles are blown onto a horizontal bar and stacked there until removed.

ALARM

A light beam (visible or invisible) striking a phototube is intercepted and an alarm signal is given. The light beam can be lengthened by means of mirrors. The interception may be caused by persons, approaching trains, traffic, etc.

ASTRONOMY

Photometers are used in this science for measuring light intensities or spectral emission of stars or other celestial bodies. With photomultipliers still better results can be obtained.

AUTOMATIC LIGHT SWITCHING

One or more phototubes operating relay circuits, biased at a certain level, are directed towards the sky. As soon as daylight decreases to a certain level, artificial illumination is switched on by the relay. When daylight increases the illumination is automatically switched off. Some delaying device is incorporated in the circuit, to prevent the relay from being operated as a result of passing foreign bodies intercepting the light received by the phototubes.

AUTOMATIC AUTODIMMING

In our modern busy traffic it requires very much attentiveness of the driver at night to dim accurately and in time.

An automatic dimmer can relieve the driver of this distracting task, in order to give him more chance to concentrate on the road.

It is consequently well possible, that in the years to come this application may become very important, especially for photomultipliers or semi-conductor photo sensitive devices.

BAKING COLOUR CONTROL

In order to obtain baked products of uniform quality and to prevent burning, phototubes are installed in ovens in large bakeries or hotels. As soon as the colour of the products reaches a certain degree the current is switched off and a signal is given.

CALIBRATION OF GAS AND WATER METERS

In gas and water meters the quantity used is measured by registering the number of revolutions of a small propeller or vane, which is driven by the gas or water flow. When a meter has to be calibrated the vane revolutions are compared with those of a standard meter of the same type. The vane of the standard meter intercepts a light beam to a phototube (or reflects light to it). The pulsating voltage on the load resistor is amplified and fed to a gas-discharge lamp. This lamp illuminates the vane of the meter, and by the stroboscopic effect it is easy to control the number of revolutions so that it corresponds to that of the standard meter.

CHEMICAL ANALYSIS

In chemical analysis the phototubes can be used in flame photometers, colorimeters etc.

CHLORINATION OF WATER

Drinking water is treated with chlorine to ensure its freedom of organic impurities. This process needs careful control since insufficient chlorine fails to render the water safe for drinking, while too much chlorine gives it a disagreeable taste. A reagent can be added to samples of the water, and if the discoloration reaches a certain degree the chlorine supply can be cut off. If the required degree of discoloration is not reached extra chlorine can be added to the water. When operated by phototubes the process can be made fully automatic.

COLORIMETER

Photometer of special construction, used to analyse colour radiation either by comparison with a standard or by an absorption method.

COLOUR COMPARISON

To ascertain whether a newly made paint, ink or dye has the same colour value as that of a product previously made, a comparative measurement can be made with a spectro-photometer (see spectro-photometer).

COLOUR INSPECTION DURING ROUGH TEMPERING

In the rough tempering of metals the process can be observed by an optical pyrometer for measuring the temperature. When the correct temperature is reached, a phototube relay circuit can either give a signal or modify the process.

CONTROL OF MIXTURE OF SOLUTIONS

When a mixture has to be made of two solutions of different colour or density, the flow of the liquid can automatically be stopped when the required colour is reached. A phototube, a relay amplifier and a solenoid valve are required for this purpose.

COUNTING

Objects carried along on a conveyer, or traffic on a highway, can be counted by interception or reflection of a light beam striking a phototube. The phototube signals are amplified and passed on to an electrical counting mechanism or circuit.

DENSITY CONTROL

Corresponds to "Control of Mixture of Solutions" and to "Smoke Detection" (q.v.).

DISCOLOURING DURING CHEMICAL REACTIONS

See "Chlorination of Water" and "Control of Mixture".

DUST DETECTION

In some factories too high a dust content in the air can be dangerous to workers or may spoil production. The air is drawn off by fans and the dust content determined in the same way as with the smoke detector.

EXAMINATION FOR:

CRACKS	In paper fed to printing machines.
DOUBLE PRINTING	With printing presses.
GRINDING	With grinding machines.
INSULATION	Of enamelled wire with machines for winding coils or transformers.
LEAKS	In the latex rim in the lid of tins in canneries.
PIN HOLES	In thin plates made in rolling mills.
POLISHING	With automatic polishing machines.
SEAMS	With textile machines.
SPRAYING	With automatic spraying machines. Can be carried out with the aid of phototubes either with direct or with reflected light.

EXPOSURE CONTROL (X-RAY)

In X-ray apparatus for mass examination automatic exposure control is built in. A phototube (or a photomultiplier) measures the amount of light on a fluorescent screen and via auxiliary apparatus controls the exposure.

EXPOSURE METER

Exposure meters are used in photographic reproduction. The phototube measures the light intensity, and automatic exposure control can be incorporated in the installation.

FACSIMILE

A scanning head comprising a phototube "reads" a text or photograph mounted on a rotating drum. It translates the reflected light intensities of the original in current variations which are amplified and used for modulating a transmitter.

At the receiver end a drum rotating in synchronism with the transmitter drum is used. The modulation is transferred by chemical means to a specially prepared paper.

When more sensitivity is required a photomultiplier must be used.

FILLING CONTROL

In a filling machine a phototube "watches" the filling of bottles or jars. When the required level is reached the phototube signal causes the flow of liquid to stop. The filled bottles are usually automatically replaced by empty ones.

FINAL INSPECTION

Finished products often have to be examined to make sure that they are not sent out without labels, trade marks, etc. This inspection can be carried out with the aid of a phototube installation.

FIRE ALARM

Normally there is a considerable development of smoke before a blazing fire starts. A phototube smoke detector placed in an air-conditioning duct is used to give a fire alarm (see "Dust Detection" and "Smoke Detection").

FLAME CONTROL

When in boilers or furnaces the fuel is oil or coal dust, extinguishing of the flame may cause an explosion if the fuel supply is not immediately stopped. A phototube watches the fire and in the absence of a flame a signal is given and the fuel supply is cut off.

FLAME PHOTOMETERS

To detect whether a material contains a certain element, a small amount of it is burned in a flame. If it shows the characteristic spectral line, which can be observed by a selective photometer, the element in question must be present in the material.

FOLDING

In laundries, printing offices, etc. goods have to be folded. When the leading edge of the material intercepts the light beam to a phototube, the latter brings the folding mechanism into operation.

GAS DETECTION

To detect the presence of dangerous gases in air, the air can be drawn off and compressed. The compressed air can be compared with pure air in different containers (phototube bridge circuit) or it can be lead through a liquid which changes colour when poisonous gas is present. The chemical reaction can be observed by a phototube.

GRINDING INSPECTION

See "Examination".

IMAGE REPRODUCTION

In the so-called flying spot scanning system for televising films a phototube is used to convert the light variations into current variations. In modern flying spot scanners for use in television a photomultiplier is used.

INTEGRATING PHOTOMETERS

Photometer used to obtain integration of light exposures over a certain period.

LEVEL CONTROL

Level control can be either obtained by watching a gauge glass by means of a light beam on a phototube or in the manner described under "Filling Control".

MERCURY-VAPOUR DETECTOR

See "Gas-Detection".

METEOROLOGY

The extent to which clouds or haze intercept the sunlight is a measure for their density or composition. These factors can be measured with a photometer.

MIXING COLOUR

When inks, paints or dyes have to be mixed, to obtain the same colour as previously used, the eye is not sufficiently sensitive to distinguish fine differences in colour. When the new mixture is compared with the former one with the aid of a spectrometer, the analysis into different components shows whether the new mixture is identical or, if not, which colour has to be added.

OPTICAL PYROMETER

This is used for ascertaining the surface temperature of heated metals or ceramics. Means are usually provided for automatically registering the temperature on a chart. The energy radiation of an incandescent body is approximately proportional to the fourth power of the absolute temperature.

PIN HOLE DETECTOR

Thin metal sheets coming from the rollers can be examined for pin holes by passing them over a light source and inspecting the surface with the aid of a row of phototubes or what is called an aniseikon. Faulty sheets can automatically be removed.

PHOTOGRAPHIC DENSITY

The density on film can be measured by testing it with light from a gas-discharge lamp. The light, having a pulsatory character causes an A.C. voltage across the load resistor of a phototube. The meter indicating the A.C. voltage can be directly calibrated in degrees of density or be used for comparison only.

POLISHING MACHINES

See "Examination".

REGISTER CONTROL

Phototube method for controlling rotary presses, for cutting, gluing, labelling, folding, etc. at the correct place on the already printed material.

SAFEGUARD

When heavy presses, punches drills, etc. are fed with the material by hand, a phototube locking device can be used to prevent the operator from being seriously hurt by the machine. As long as a light beam to the phototube is interrupted by the hands or other parts of the body the machine is locked. Failure of phototube or light source locks the machine too.

SATURATION MEASURING

If a solution is saturated the density has a certain value, which can be measured with a photometer.

SMOKE DETECTION

Since smoke indicates waste of fuel, it saves money to be warned when the fire produces smoke. A phototube and light source are mounted opposite each other in the chimney stack. As soon as the smoke reaches a certain density, the phototube brings a relay into action and a bell or buzzer is heard. The stoker regulates the fire and the signal stops as soon as the fire burns properly.

SORTING TO COLOUR

Different methods are used for sorting with the aid of phototubes. Cigars can be sorted to colour, coffee beans, oranges, etc. according to their quality. Filters are used to make the phototube sensitive to one special colour. Faulty specimens of the products under inspection are automatically removed.

SOUND REPRODUCTION

Recording of sound on film is either done photographically (sound film) or mechanically by cutting a track with variable width in blackened tape (Philips Miller). The reproduction is possible by moving the film or tape at a uniform speed between a light source and a phototube.

SPECTRAL ANALYSIS

See "Colorimeter", "Flame Photometer" and "Spectrometer".

SPECTROMETER

Phototube instrument for measuring the amount of direct or reflected light of a certain colour. The different colours can be selected by selective filters or by using monochromatic light sources.

SWITCHING OF HEAVY CURRENTS

The phototube circuit can control not only relays but transductors as well. This is of importance when heavy currents have to be switched or controlled. Transductors have the advantage over heavy relay switches in that there are no moving parts or burning contacts. Furthermore they operate silently. For register control or temperature control transductors can be used.

TEMPERATURE CONTROL

A thermometer can be watched by a phototube to keep temperatures constant. See further "Colour Inspection, "Rough Tempering" and "Switching of Heavy Currents".

WEIGHING

Automatic weighing can be done with phototube circuits. The phototube watches the pointer of a weighing machine or scale.

PART 2

Practical applications and Circuit descriptions

PHOTOTUBE APPLICATIONS

When a light signal has to be converted into a switch manipulation, a phototube offers a fairly simple solution. Unfortunately the anode-current variations of a phototube are too small to operate even the most sensitive relay, so that amplification is necessary.

Especially when phenomena of a slow character have to be registered or controlled, the amplifier can very often be of simple design. In such cases, the exciter lamp, the amplifier and even the phototube can be fed directly from the a.c. mains or from a simple and inexpensive mains transformer. In other applications, however, d.c. supply is often required for all elements in the circuit, even for the exciter lamp. Then a more complicated amplifier must be advised. In this chapter various phototube amplifiers and relay circuits will be described together with some industrial applications.

A UNIVERSAL ELECTRONIC SWITCH FOR INDUSTRIAL PURPOSES

Fig.38 shows the diagram of a very elaborate circuit for photoelectric counting and control. The functions of the several components are as follows:

(a) The double switch S_1 offers the possibility of changing-over from a "light" circuit (in which case the relay is operated by light impinging on the photocathode) to a "dark" circuit (in which case the relay is operated by darkness).

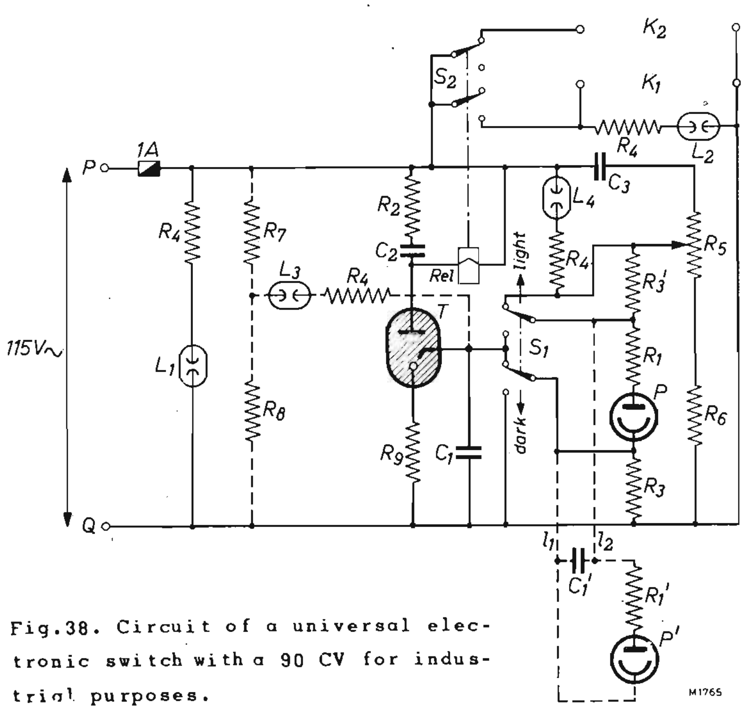


Fig.38. Circuit of a universal electronic switch with a 90 CV for industrial purposes.

PARTS LIST

R_1 =	1 MΩ,	½ W
$R_{1'}$ =	1 MΩ,	½ W
R_2 =	1 kΩ,	½ W
R_3 =	30 MΩ,	½ W
$R_{3'}$ =	10 MΩ,	½ W
R_4 =	200 kΩ,	½ W
R_5 =	500 kΩ,	½ W
R_6 =	1 MΩ,	½ W
R_7 =	100 kΩ,	½ W
R_8 =	220 kΩ,	½ W
R_9 =	1 kΩ,	½ W
C_1 =	120 pF	
$C_{1'}$ =	120 pF	
C_2 =	6 μF	
C_3 =	0.022 μF	
T =	5823	
$P = P'$ =	90 CV	
L_1 - L_4 =	Z8	

(*b*) By incorporating the capacitor C_3 a certain leading phase shift (α in Fig.39) is introduced between the trigger voltage and the anode voltage of the 5823, thus ensuring that the duration of the current pulse flowing through the relay (β in Fig.39) is a maximum.

(c) A more reliable action is obtained by using a 15 000 Ω relay instead of the normally used 2000 Ω relay, especially in respect of fluttering at small light intensities.

(*d*) The resistor R_9 of 1 kΩ has been incorporated in the cathode circuit of the 5823 to limit the peak starter current and to provide the required voltage difference between the switching-on and -off voltages.

(e) The sensitivity of the apparatus is adjustable by varying the phototube voltage, by means of the potentiometer R_5.

(*f*) The resistor R_3 of 30 MΩ has the function of a leak resistor for the capacitor C_1, thus rendering the discharge time of C_1 more constant in the "light" circuit. In the "dark" circuit R_3' forms a potential divider with C_1.

In the "light" circuit, i.e. when the switch S_1 occupies the position indicated in Fig.38, the operation is based on the rectifying effect of the phototube when it is illuminated. The capacitor C_1 is then gradually charged by the current flowing through the phototube until the trigger breakdown voltage has been reached.

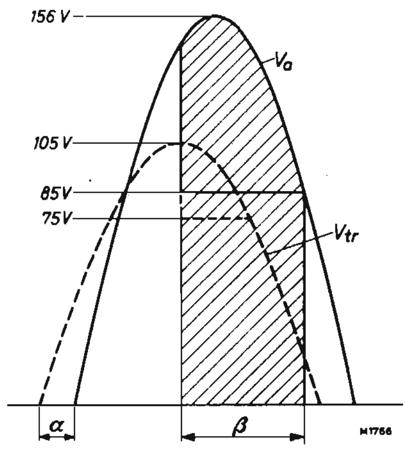


Fig.39. Anode and starter voltage of the 5823, α = leading phase angle, β = anode current angle.

The operation of the "dark" circuit is based on a different function of the phototube, which then forms a variable leak resistor for the capacitor C_1. When the phototube is illuminated the discharge current through the phototube is so large that the remaining voltage across C_1 is too low to trigger the 5823. The difference between the two circuits therefore amounts to the high resistors and the phototube (with the protecting resistor R_1) being interchanged.

The neon pilot lamps L_1 and L_2 have the following functions. The lamp L_1 indicates whether the mains voltage is switched on, whereas L_2 shows whether the relay is energized. In the latter case the mains voltage appears at the plug sockets K_1, whereas in the non-energized condition the mains voltage appears at the sockets K_2.

The circuit drawn in dashed lines provides for the case that the phototube is mounted at some distance from the electronic switch, the apparatus being used for example as a flame control. In this case provision must be made that a warning is given when a short-circuit occurs in the long cable towards the phototube. For the "light" circuit (flame control) this is achieved by means of the neon pilot lamp L_4 and in the "dark" circuit (twilight switch) by means of the neon pilot lamp L_3. If the capacitance C_1' of the cable is fairly large in the "dark" circuit this can be compensated by reducing the capacitance C_1 accordingly.

PHOTO-ELECTRIC RELAY

Fig.40 shows the lay-out of a simple a.c. fed photo-electric relay. It can be used in installations in which an action has to take place as a consequence of the appearance or disappearance of light. The operation of the circuit can be explained as follows. Assume that the photo electric tube is not exposed to light, thus no current flows through resistor R_1. The control-grid voltage of the PL2D21 is now solely determined by the voltage derived from the potentiometer R_3: this voltage is in anti-phase with the anode voltage. R_3 is so adjusted that the tube does not ignite.

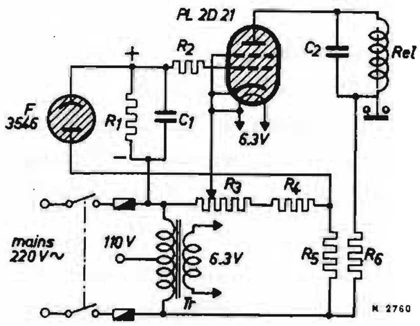


Fig.40. Photo-electric relay circuit operated by a.c. supply.

Parts List:

R_1 =	1 MΩ	R_5 =	60 kΩ
R_2 =	0.1 MΩ	R_6 =	1 kΩ
R_3 =	5 kΩ	C_1 =	0.01 μF
R_4 =	20 kΩ	C_2 =	2 μF
		Rel =	relay 15 kΩ

When the phototube is exposed to light a voltage drop with the polarity indicated will be produced across R_1. The control-grid of the PL2D21 will consequently become more positive, the tube will ignite and relay *Rel* will be energized. Relay *Rel* has been shunted by capacitor C_2, whilst a current-limiting series capacitor R_6 is also included.

A SIMPLE PHOTO-ELECTRIC RELAY

The simple photo-electric relay shown in Fig.41 may be used for counting objects in mass production, for automatic dooropening devices, for supervising manufacturing processes, etc.

The supply transformer may be of the type with primary tapping as commonly used in radio receivers.

The device is equipped with a 90 AV phototube, whilst the magnetic relay is energized by an E 80 L pentode. The working point of the latter tube can be adjusted by means of the 50 kΩ potentiometer.

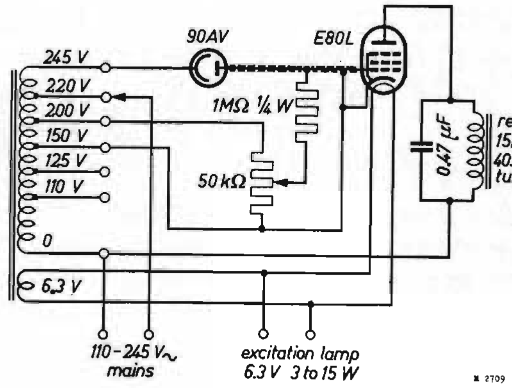


Fig.41. Circuit diagram of the photo-electric relay with the 90 AV.

DELAYED-ACTION PHOTO-ELECTRIC RELAY

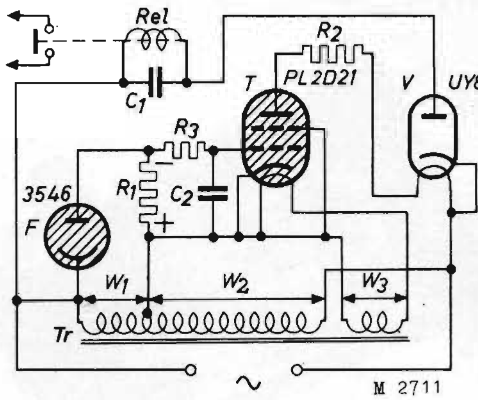
Fig.42 shows the lay-out of a light-controlled, delayed-action relay, which at dusk can switch on certain loads such as indoor or outdoor lighting, illuminated advertisements or landing beacons

for aircraft, and switch them off at daybreak. This simple relay is a.c. fed via the small transformer *Tr*, winding w_1 and w_2 of which feed the phototube *F* and the anode circuit of the PL2D21 respectively. The circuit operates only during the half cycles in which the right-hand ends of the windings w_1 and w_2 are positive.

Fig.42. Photo-electric relay with delay

Parts List:

R_1 = 1 MΩ
R_2 = 800 Ω
R_3 = 50 kΩ
C_1 = 2 μF
C_2 = 500 pF
T_r = mains transformer
$w_1 + w_2$ = 220 V
w_1 = 60 V
w_3 = 6.3 V
Rel: relay 15 kΩ



When the phototube is exposed to light a voltage drop occurs across resistor R_1, as a consequence of the current flowing through the phototube; the voltage drop has the polarity indicated in the figure. As a result, the thyratron is negatively biased, which prevents it from igniting. If, however, at dusk the light falling on the phototube decreases considerably and the current through R_1 therefore becomes low, the negative grid voltage of the thyratron decreases accordingly. This causes the tube to ignite, and current will commence to flow through the heater of the indirectly heated rectifier *V*.

After a certain delay the cathode of *V* will start to emit electrons so that the tube will pass current and the relay *Rel* is energized, thus closing the external circuit. The delay, caused by the warming-up of the cathode of *V*, results in the relay being set in operation only by the normal, gradual variations of the lighting and not by incidental fluctuations which can be caused, for example, during the day by aircraft or, at night, by lightning flashes.

PHOTO-ELECTRIC RELAY WITH PRE-AMPLIFIER

The circuits described above may be too insensitive for igniting or extinguishing the PL2D21. This difficulty can be overcome by

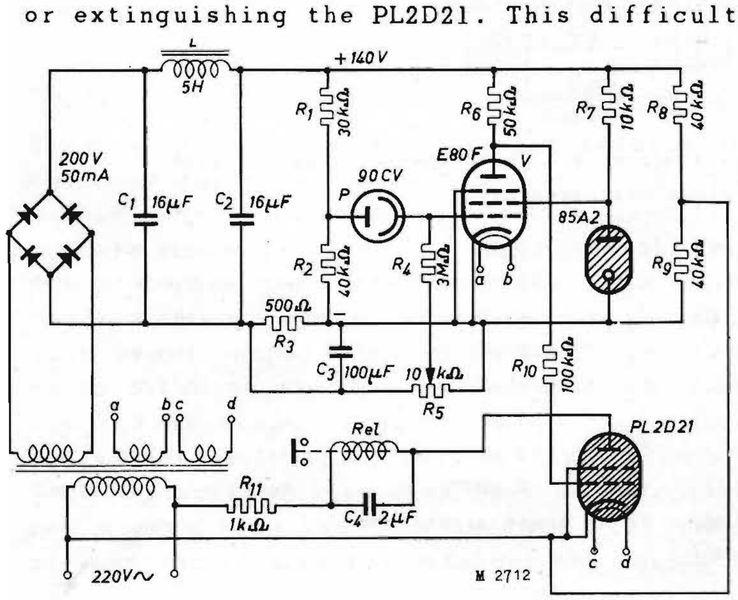
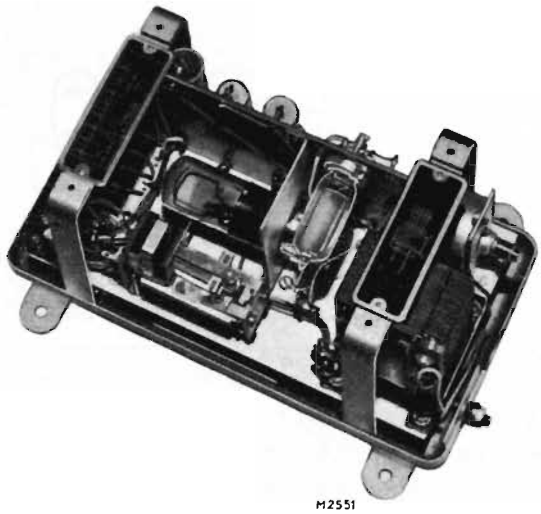


Fig.43. Circuit diagram of a photo-electric relay with pre-amplifier.

43

using a relay in combination with a pre-amplifier. Such a circuit is shown in Fig.43. When the phototube is exposed to light the grid of the pentode E 80 F becomes less negative so that the output voltage of the bridge circuit formed by the tube *V* and the resistors R_6, R_8 and R_9 becomes negative, the PL2D21 cannot ignite. However, as soon as the beam of light directed towards the phototube is interrupted, the thyratron ignites.



The screen-grid voltage of the pre-amplifier tube *V* is stabilized at 85 V by the tube 85 A 2; in this way the circuit is practically independent of mains voltage fluctuations. Fig.44 shows a practical example of such a photo-electric relay.

Fig.44. Photograph of the photo-electric relay.

PHOTO-ELECTRIC CONTROL

By means of the circuit shown in Fig.45 it is possible to maintain a physical quantity between two desired limits. For this purpose this quantity has to be converted into a corresponding luminous

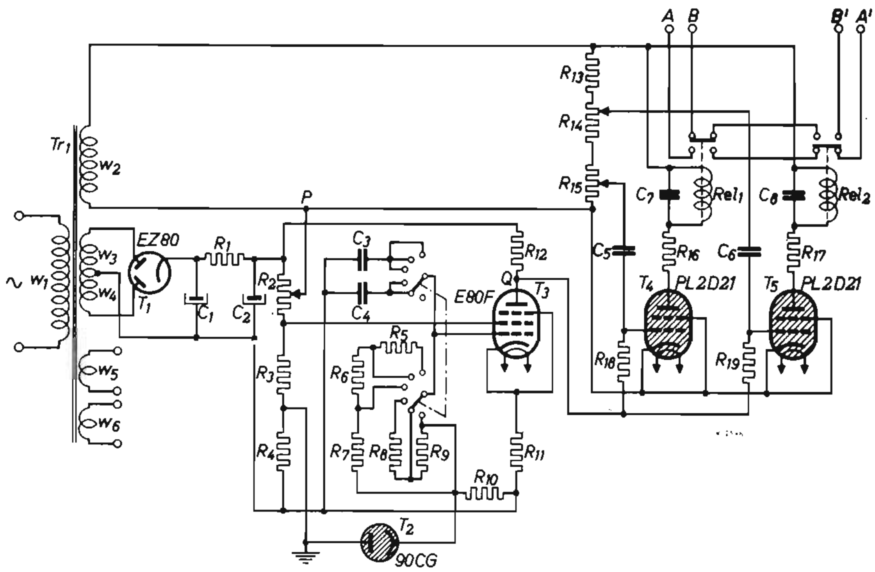


Fig.45. Circuit diagram of a photo-electric control with maximum and minimum adjustments.

Parts List

	R_{10} = 1 MΩ	C_1 = 50 μF	w_1 = 220 V
R_1 = 10 kΩ	R_{11} = 2 kΩ	C_2 = 50 μF	w_2 = 110 V
R_2 = 100 kΩ	R_{12} = 100 kΩ	C_3 = 4 μF	w_3 = 265 V
R_3 = 22 kΩ	R_{13} = 200 kΩ	C_4 = 0.5 μF	w_4 = 265 V
R_4 = 33 kΩ	R_{14} = 100 kΩ	C_5 = 5000 pF	w_5 = 6.3 V
R_5 = 3 MΩ	R_{15} = 100 kΩ	C_6 = 5000 pF	w_6 = 6.3 V
R_6 = 1.5 MΩ	R_{16} = 500 Ω	C_7 = 2 μF	*Rel*.1 = relay 15 kΩ
R_7 = 1.5 MΩ	R_{17} = 500 Ω	C_8 = 2 μF	*Rel*.2 = relay 15 kΩ
R_8 = 3 MΩ	R_{18} = 1 MΩ	*Tr* = mains transformer	
R_9 = 3 MΩ	R_{19} = 1 MΩ		

intensity, which impinges on the phototube T_2. With this method very small currents, for example, can be kept constant by means of a mirror galvanometer.

The phototube is incorporated in a bridge circuit (see Fig.46), one branch of which is formed by T_3, a pentode pre-amplifying tube. The difference between the voltage across R_{12} and that across the upper part of the potentiometer R_2 is applied as a negative bias to the grids of the two PL2D21 thyratrons T_4 and T_5. On this direct voltage two alternating voltages of different amplitudes are superimposed; these can be adjusted by R_{14} and R_{15} and are fed to the grids of T_5 and T_4 respectively. R_2, R_{14} and R_{15} are so adjusted that, with light of average intensity falling on the phototube, thyratron T_5 is ignited, whereas T_4 remains extinguished (Fig.47). The positions of the relays incorporated in the anode circuits of the thyratrons are then as shown in Fig.45. In these positions the external circuits AA' and BB' are both interrupted. When the intensity of the light falling on the phototube increases, the negative grid voltage of the two thyratrons also increases (vertical control), causing T_5 to extinguish and circuit BB' to be closed. When the luminous intensity decreases, the bias of the thyratrons also decreases, and T_4 will also ignite, causing the circuit AA' to be closed. To counteract the variation of the quantity which is to be kept constant, it is possible to incorporate, for example, a heating element, electromagnets or a motor with two directions of rotation in the circuits AA' and BB'. To prevent the circuit from reacting to momentary variations in the lighting, a delay circuit is incorporated in the grid network of the E 80 F. This consists of an RC filter, the time constant of which is variable in five steps, viz. 0, 1½, 3, 12, 24 sec.

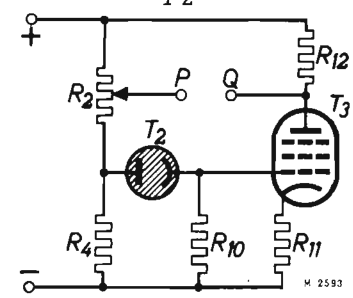


Fig.46. The bridge circuit of Fig.45.

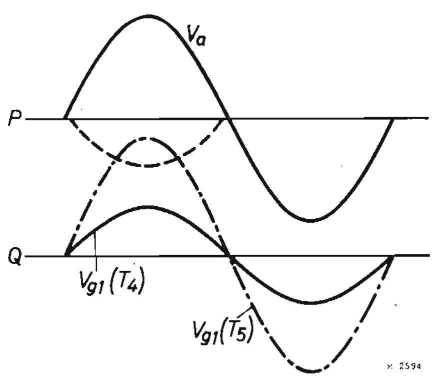


Fig.47. Anode supply voltage and grid voltages of the thyratrons T_4 and T_5 of Fig.45 at an average illumination of the phototube T_2.

COLOUR DENSITY AND BRIGHTNESS CONTROL DEVICE

When in printing offices, in the textile or in the chemical industries colouring-matter or dyes are produced or used, it is as a rule necessary to ensure that the density and brightness of the colours are not subject to any noticeable differences. Even when the processes are supervised by an expert, the occurrence of such differences cannot be avoided, due to fatigue of the eyes. For this reason an electronic control device has been developed by means of which the density and brightness of the colour involved are continuously compared with a reference sample. By using a bridge circuit, supply voltage fluctuations and variations of the light source which is used have no effect whatsoever. The device has a very high sensitivity, and will detect minor differences between the reference sample and the sample to be tested.

CIRCUIT DESCRIPTION

Fig.48 shows the circuit diagram of the control device. Two identical phototubes, P_1 and P_2, are used; the reflected light from the reference sample impinges on the cathode of one phototube, whilst the reflected light from the sample under test impinges on the cathode of the other phototube. Either blue-sensitive phototubes type 90 AV or red-sensitive phototubes type 90 CV should be used, according to the purpose in view. The anodes of the phototubes are connected to the control grids of two special-quality pentodes E 80 F. The cathodes of the phototubes are fed with a direct voltage of -85 V which is stabilized by means of a voltage reference tube 85 A2. The load resistances are formed by the grid leak resistors of the two pentodes. These tubes are balanced by means of a 10 kΩ potentiometer which is connected between their anode load resistors. The screen grids of the pentodes are fed from a potential divider, but their anodes are connected to the 300 V supply voltage via 0.1 MΩ resistors and the balancing potentiometer.

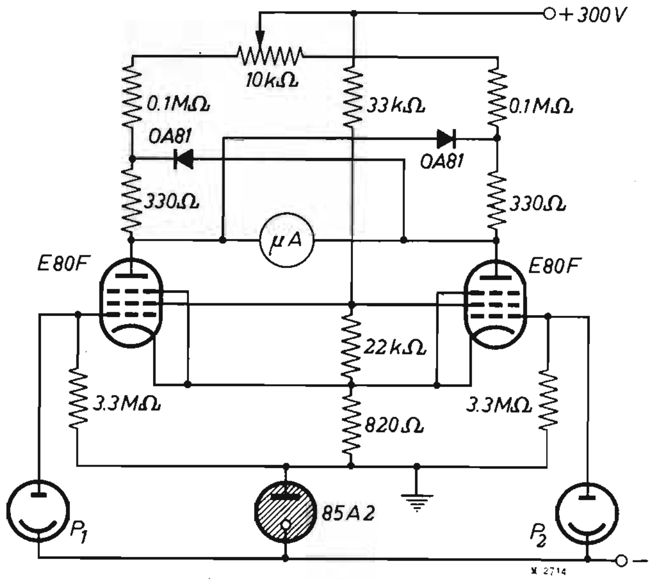


Fig.48. Circuit diagram of the control device. The phototubes P_1 and P_2 may be of the 90 AV or of the 90 CV type.

A centre zero microammeter with a range of 50-0-50 μA is connected between the two anodes. This instrument is safeguarded against overloading by connecting biased germanium diodes OA 81 in both directions across its terminals. The bias voltages for these diodes are produced across 330 Ω resistors included in the anode circuits of the pentodes.

The direct supply voltage can be obtained by means of a selenium rectifier type SR 250 B 100 and a smoothing filter

OPERATION

The control device is first balanced by illuminating a sample with diffuse light, so that the quantities of reflected light impinging on the phototubes are equal. The same voltage drop will thus be produced across the grid leak resistors of the pentodes. Small differences between the phototubes and the pentodes can be compensated by means of the potentiometer. When the bridge is exactly balanced the currents flowing through the pentodes will be equal and the same voltages will be produced across their anode load

resistors, so that the centre zero instrument will be in its neutral position. If the control device is completely unbalanced there is no risk of the instrument being overloaded; for in that case the bias of one of the germanium diodes will be exceeded, as a result of which it becomes conducting, limiting the current which flows through the instrument to a safe value.

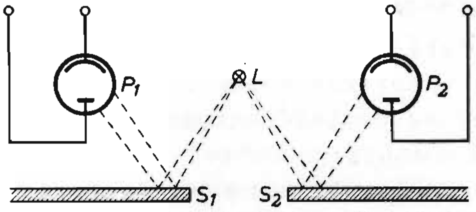


Fig.49. Set-up of the measuring device. S_1: reference sample, S_2: sample under test, L: light source.

After the control device has been balanced, the reference sample remains opposite one phototube, whereas the sample under test is placed opposite the other phototube, both samples being illuminated by the same light source (see Fig.49).

SENSITIVITY

Due to a bridge circuit being used, mains voltage fluctuations of ± 10% have no influence and variations of the light source will not affect the measuring results either, since it illuminates both samples simultaneously. It is convenient to provide the scale of the instrument with reference marks which correspond to the permissible deviations of the samples under test.

A deflection of 50 μA will be obtained at a grid bias of 60 mV. Since the grid leak has a value of 3.3 MΩ, this corresponds to a variation of the photo-electric current of 1.8×10^{-8} A, i.e. in the case of the phototube 90 CV a variation of the luminous flux of approximately 1.8×10^{-5} lumen will still give a clear reading.

MEASURING EXPOSURE TIMES OF CAMERAS

INTRODUCTION

It is only by electronic methods that is has become possible to measure exposure times of cameras. These methods were until recently usually based on one of the following two principles.

(a) Integration method

According to this method a beam of light passes through the photographic shutter and impinges on a phototube. The resulting photoelectric current, which is obviously proportional to the luminous flux transmitted by the shutter, is used for charging or discharging a capacitor. The actual exposure time can be evaluated from the ratio of the voltages across the capacitor before and after the shutter has been operated.

This method has the disadvantage of being impracticable for measuring extremely short exposure times. It is, moreover, a quantitative measurement which depends on various factors such as the luminous flux of the light source, the sensitivity of the photoelectric cell and the supply voltages. Calibration is rather difficult and requires a standard shutter the exact exposure times of which are known.

(*b*) Oscillograph method

This method differs from that described under (*a*) in that the voltage across the phototube is displayed by a cathode-ray oscilloscope. By modulating the electron beam of the cathode-ray tube with a known frequency a time reference is obtained, so that it is possible to ascertain the operation of the shutter as a function of time with great accuracy.

Very good results are obtained by this method, which also gives information on the exact variation of the luminous intensity passed by the shutter. The main disadvantage is, however, that its use is restricted to laboratories because the image displayed on the cathode-ray tube must be photographed to be studied.

In this paper a third method is discussed. Use is made of the decade counter equipped with E 1T counter tubes. According to this method the exposure time is indicated directly by the E 1T decade counter tubes. The installation offers the particular advantage of being very simple, so that it can be used in the workshop for checking cameras during mass production. Its calibration by means of a stopwatch is extremely simple.

PRINCIPLE OF OPERATION

Fig. 50 shows the principle of operation of this method. The light emitted by the light source *S* is projected on the film gate of the camera *P* via condenser lens *L*. For checking focal plane shutters a special diaphragm *D*, which is dealt with later, must be fitted against the film gate. The light transmitted by the shutter impinges on the phototube *T*, which controls the gating circuit *G* to which the oscillator *O*, producing a signal of a known frequency, is also connected.

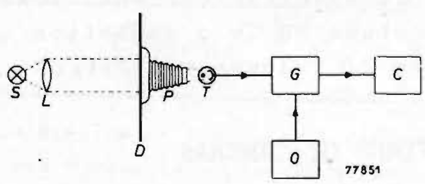


Fig. 50. Set-up of the measuring equipment for camera shutters. *S*: light source, *L*: condenser lens, *D*: special diaphragm for measuring focal plane shutters, *P*: camera, *T*: phototube, *G*: gating circuit, *O*: oscillator, *C*: decade counter.

So long as no light is transmitted by the shutter, no photoelectric current is produced by the phototube and the gating circuit prevents the oscillator signal from being applied to the decade counter *C*, but when the shutter is opened so that the phototube is illuminated, the gating circuit passes the counting pulses produced by the oscillator to the decade counter, which starts to register the number of pulses applied. If the oscillator produces a signal of 10 000 c/s the counter will indicate the exposure time in ten-thousandths of a second.

The accuracy of this method is extremely high, variations of the light source and mains voltage fluctuations having no effect whatsoever. This is due to the fact that the device does not react to the *amplitude* of the signal but to the *absence* or *presence* of the photo-electric current.

In the first instance the accuracy depends on the constancy of the oscillator frequency, which can easily be kept within 2 %. This frequency can, moreover, be checked with great accuracy in the following, very simple manner by means of a stopwatch. The camera shutter is opened during a fairly long period, for example 50 sec, to reduce the error which is introduced by inaccurate reading of the stopwatch. When the oscillator has been correctly adjusted, so that it operates at exactly 10 000 c/s, the decade counter will indicate the number 500 000.

Due to the fact that only complete counting pulses are registered by the decade counter, there may be an inaccuracy of plus or minus half a cycle. When very short exposure times must be determined with great accuracy it may therefore be advantageous to choose a somewhat higher oscillator frequency of, say, 20 000 c/s to 30 000 c/s.

CONSTRUCTIONAL DETAILS

Checking focal plane shutters

As previously mentioned, a special diaphragm must be used for checking focal plane shutters. In order to measure the exposure time at a given point in the focal plane this diaphragm should be provided with a very narrow slot which must be exactly parallel to the slot of the shutter.

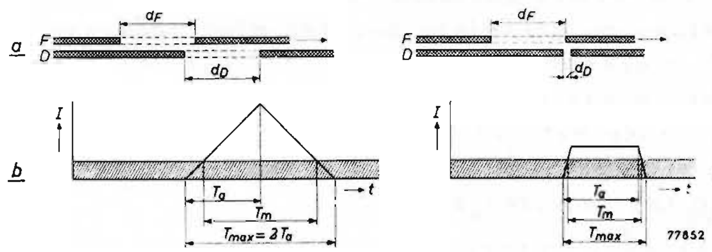


Fig.51. Influence of the width d_D of the slot of the diaphragm D on the accuracy of the measurement. F represents the focal plane shutter and d_F its slot. T_a: actual exposure time of an elemental area of the film, T_m: measured exposure time, T_{max}: value of the measured exposure time if no threshold (hatched area) were present.

This may be explained by means of Fig.51. F denotes the focal plane shutter which is assumed to travel to the right and D represents the diaphragm. The interval during which light passes through the slots is given by the expression:

$$T_{max} = (d_F + d_D)/v$$

where v denotes the rate of travel of the focal plane shutter, d_F is the width of the slot of the shutter and d_D that of the diaphragm. The actual exposure time of an elemental area of the film is on the other hand:

$$T_a = d_F/v.$$

Since the photo-electric current I must exceed a certain level to operate the gating circuit, there will be a threshold below which the counting pulses produced by the oscillator are not passed by

the gating circuit and the decade counter remains inoperative (hatched areas in Figs 51*b* and 51*d*), although some light passes through the two slots.

When d_D is made equal to d_F (Fig.51*a*), the situation represented in Fig.51*b* will arise. The quantity of light transmitted, and thus also the photo-electric current I, will gradually increase until the two slots coincide, after which this current gradually drops back to zero. Depending on the threshold value, the measured exposure time T_m may therefore range from almost T_{max}, i.e. twice the actual exposure time T_a, to zero, so that the results are influenced to a large extent by conditions such as the luminous flux of the light source, the sensitivity of the phototube and the adjustment of the gating circuit.

The slot of the diaphragm should therefore be made no wider than necessary to ensure that a photo-electric current of sufficient strength is produced to control the gating circuit.

This situation is represented in Figs 51c and 51*d*, where d_D = 1/10 d_F. The photo-electric current I now rises to a value exceeding the threshold value and remains constant during an interval $(d_F - d_D)/v$, after which it drops back to zero. The extreme limits between which the measured exposure time T_m may range are now much narrower, namely T_{max} = 1.1 T_a and T_{min} = 0.9 T_a, the dependence on the threshold value being greatly reduced.

Particular care should be taken to ensure that the slots run truly parallel, since an obliquely mounted diaphragm corresponds to a slot having a greater effective width. For this reason there is little point in making the slot any narrower than is consistent with the accuracy with which the diaphragm can be applied to the camera, nor should the slot be made any longer than necessary for transmitting the required quantity of light.

Good results were obtained with a diaphragm having a slot of 0.1 mm x 10 mm. The quantity of light impinging on the phototube proved to be sufficient to operate the gating circuit, a Photolita lamp type SM 250 W with condenser lens being used. The phototube should be mounted close to the camera and provision must be made to prevent dispersed light from impinging on the photocathode. A phototube type 90 AV was used, the sensitivity curve of which is in good agreement with the spectral distribution curve of the Photolita lamp. (To increase the sensitivity it is not permissible to use a gas-filled phototube, since as a result of its deionisation time difficulties would then be experienced when very short exposure times are measured.)

A convenient way of producing a diaphragm with a narrow slot is to cement two suitable razor blades by means of an adhesive such as "Araldite" on to a glass plate under a microscope. This having been done, a second glass plate is cemented on to the plate with the blades to prevent them from oxidizing. Care should be taken that the blades are well cleaned and that the edges are smooth and undamaged. Since the speed of travel of a focal plane shutter is not as a rule uniform, the measurement should be carried out at the centre of the film gate.

Checking pivoted blade shutters

Since no diaphragm is required in this case, the light source should be reduced to prevent the gating circuit from being over-

loaded. The film gate of the camera should be illuminated in its entirety and the diaphragm of the camera should be kept at a medium position, so that an average of the actual exposure time is measured.

CIRCUIT DIAGRAM

Fig.52 shows the circuit diagram of the gating circuit and the oscillator.

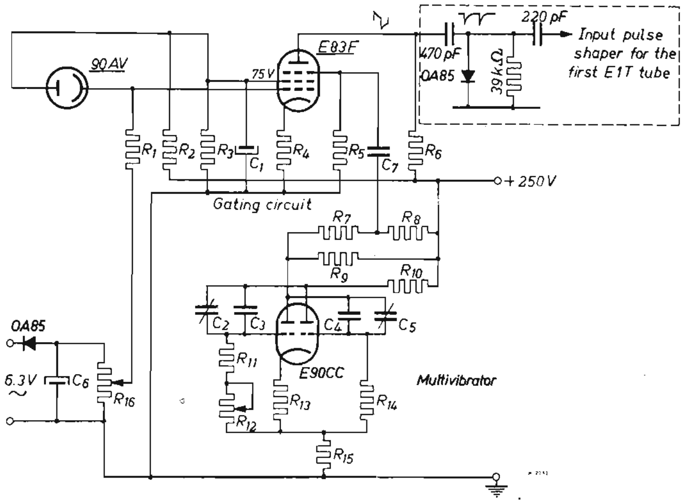


Fig.52. Circuit diagram of the gating circuit and multivibrator.

COMPONENT VALUES

R_1 = 2.2 MΩ, 1/4 W	R_9 = 3.3 kΩ, 1 W	C_1 = 25 μF, 300 V
R_2 = 15 kΩ, 3 W	R_{10} = 3.3 kΩ, 1 W	C_2 = 3-30 pF
R_3 = 8.2 kΩ, 1 W	R_{11} = 0.22 MΩ, 1/4 W	C_3 = 100 pF
R_4 = 150 Ω, 1/4 W	R_{12} = 20 kΩ, carbon	C_4 = 100 pF
R_5 = 0.33 MΩ, 1/4 W	R_{13} = 1.2 kΩ, 1 W	C_5 = 3-30 pF
R_6 = 22 kΩ, 1 W	R_{14} = 0.22 MΩ, 1/4 W	C_6 = 100 μF
R_7 = 39 kΩ, 1/4 W	R_{15} = 3.9 kΩ, 3 W	C_7 = 470 pF
R_8 = 10 kΩ, 1/4 W	R_{16} = 10 kΩ, carbon	

In the gating circuit the phototube 90 AV is connected to the control grid of the E 83 F pentode so that the control grid of the pentode becomes less negative and the counter starts to operate when the phototube is illuminated. In order to ensure that the gating tube is cut off when the light is intercepted, an additional negative grid bias is applied. This bias is derived from a rectifying circuit formed by the filament voltage transformer (6.3 V) and incorporating a germanium diode OA 85. The point at which the E 83 F becomes conducting and the counter starts to operate can be adjusted by means of the potentiometer R_{16}.

A multivibrator equipped with a double triode E 90 CC acts as time unit. The frequency of the multivibrator is preset to 10 000 c/s by means of the air trimmers C_2 and C_5: for the fine adjustment the potentiometer R_{12} has been provided, by means of which the frequency can be varied within a range of ± 250 c/s.

The gating circuit is modulated by applying the alternating voltage produced by the multivibrator to the suppressor grid of the E 83 F via the capacitor C_7. When this tube is conducting the differentiated square-wave voltage produced at its anode is applied to the first decade counter tube E 1 T via the pulse shaper.

THE 90 AV IN A PHOTO-ELECTRIC ILLUMINATION METER

In photography it is often desirable to know the required exposure time of films that must be printed. The device, the circuit diagram of which is given in Fig.53, may be an expedient for that purpose. The circuit is equipped with the phototube 90 AV, which is mounted behind the negative so that it can be made to face the densest parts of it.

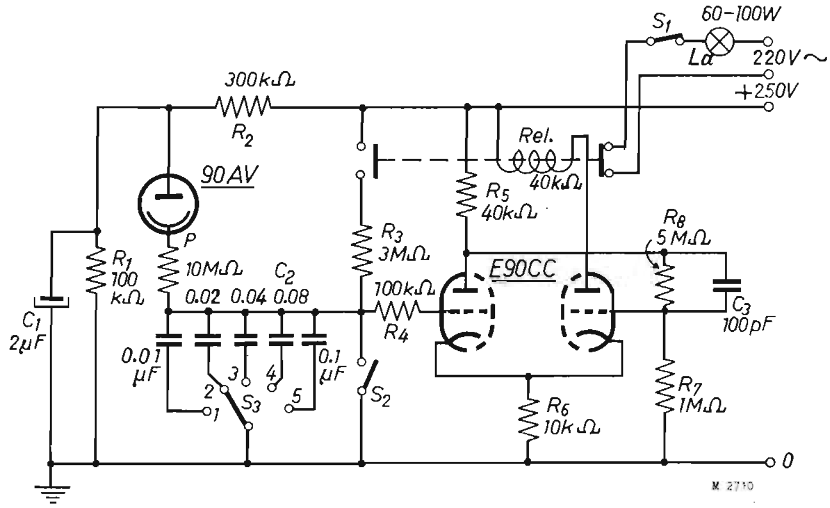


Fig.53. Photo-electric illumination meter.

Initially the switch S_1 is opened and S_2 is closed. The right section of the E 90 CC is now conductive and the left section cut off.

In order to make the exposure, S_2 is opened, whilst at the same time S_1 is closed. As a result the lamp *La* is switched on and the phototube is illuminated. Gradually C_2 is charged by the current flowing through the phototube, so that the grid of the left section of the E 90 CC becomes more positive. Finally this section becomes conductive, thereby cutting off the right section. As a result, the relay cuts out and the lamp *La* extinguishes. At the same time a second contact of the relay connects the grid of the left section of the E 90 CC to the positive supply voltage. The exposure cycle has now ended, the initial state being re-established by opening S_1 and closing S_2.

Provision is made for adapting the exposure time to the distance of the light source during enlarging and to the properties of the photo-sensitive paper. With switch S_3 in position 1 and a luminous intensity of 60 Lux on the phototube the exposure time is 0.5 sec.

When S_3 is set in position 5 the exposure time amounts to 5 sec.

The insulation resistance between the grid and the cathode of the E 90 CC is so large that at reduced illumination exposure times of 100 sec can be realized.

PHOTO-ELECTRIC ILLUMINATION REGULATOR WITH THE 90 CV

In rooms where the illumination should be kept constant and therefore be independent of ambient illumination, the circuit described below may be of advantage. In the circuit a 90 CV phototube controls the intensity of the artificial lighting, which may consist either of incandescent or fluorescent lamps.

The circuit diagram of the regulator is shown in Fig.54.

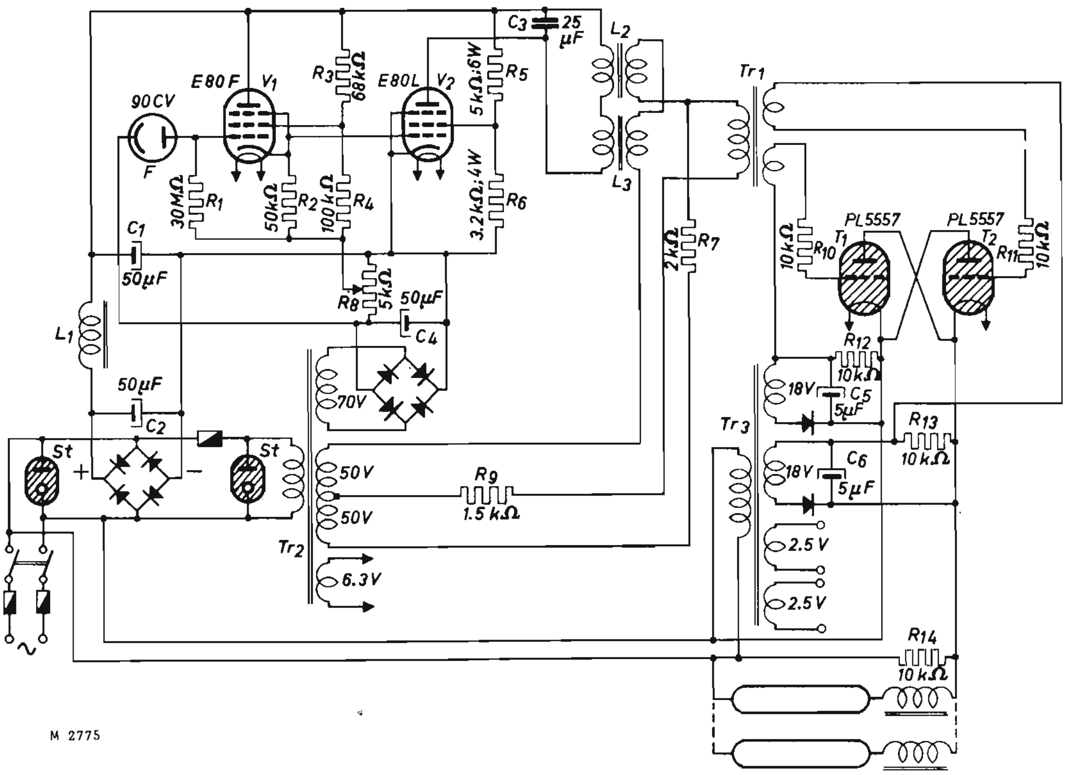


Fig.54. Circuit of an installation for automatically controlling the illumination level of fluorescent lamps, depending on the day-light. T_1 and T_2 are two PL 5557 thyratrons connected in inverse parallel.

The illumination is measured by the phototube 90 CV, which should be mounted at a suitable point. This phototube controls a d.c. amplifier equipped with an E 80 F pentode in grounded-anode circuit. The voltage variations produced across the cathode resistor R_2 are in phase with the variations of the input voltage; since, however, the two voltages have opposite effects on the grid circuit of tube V_1, the negative feedback obtained is so heavy that the gain of this tube becomes smaller than unity. This is obviously a disadvantage, but the high input resistance of the circuit is in this way changed into a low output resistance, and the heavy negative feedback moreover ensures an extremely high stability.

The output voltage of tube V_1 is applied to the E 80 L output pentode V_2. The d.c. windings of two saturable-core reactors L_2 and L_3 are included in the anode circuit of this tube, so that

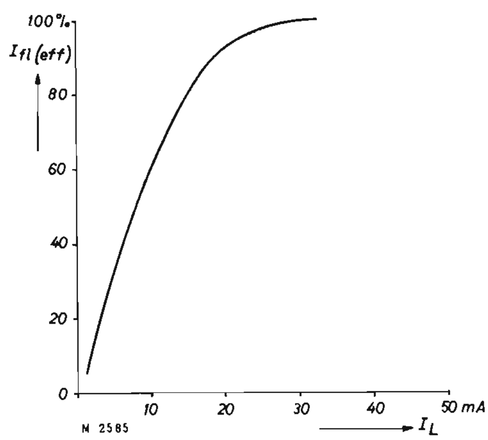


Fig.55. Current I_{fl} flowing through the lamps as a function of the premagnetising current I_L.

these reactors can be premagnetised. Their a.c. windings are connected in series in opposed directions to prevent alternating voltages being induced in the d.c. circuit. The saturable-core reactors form part of a phase-shifting network consisting of resistors and inductors.

The peaking transformer Tr_1 is connected to the output of this network, so that, at the transformer secondary, voltage pulses are produced the phase of which can be varied with respect to that of the supply voltage by varying the premagnetising current and thereby the inductance of the reactors. In this way the current I_{fl} flowing through the fluorescent lamps is controlled according to the premagnetising current I_L of the reactors, as shown in the graph of Fig.55.

When the daylight decreases at dusk, the current flowing through the phototube F also decreases, so that the grid of V_1 becomes less negative. The cathode current of this tube then increases, so that the grid of V_2 also becomes less negative, and its anode current - and hence also the premagnetising current through the reactors - increases. This results in an increase of the current flowing through the lamps according to the graph of Fig.55.

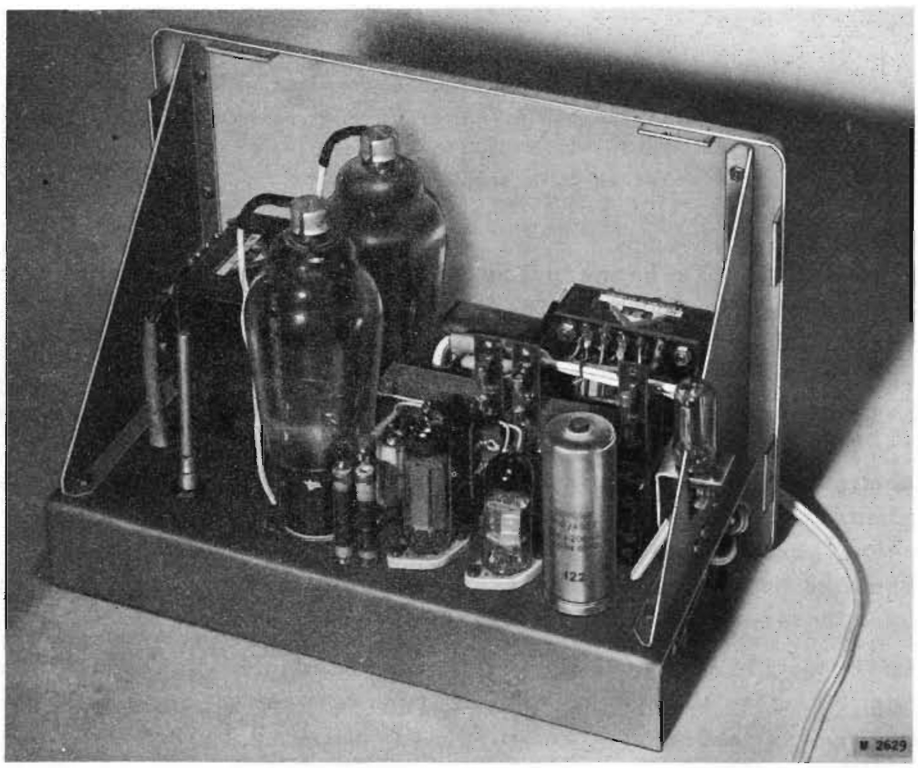


Fig.56. Experimental apparatus according to the circuit shown in Fig.54.

Fig.56 depicts the chassis of an installation constructed on these lines. The saturable-core reactors L_2 and L_3 are provided with cores consisting of special transformer laminations containing 50% nickel. The d.c. winding consists of 5000 turns of copper wire with a diameter of 0.15 mm and the a.c. winding of 1300 turns of copper wire with a diameter of 0.12 mm. Transformer Tr_1 has a core of mu-metal; its primary consists of 900 turns of copper wire with a diameter of 0.1 mm and its secondary of 2 x 1500 turns of copper wire having the same diameter.

A SMOKE DETECTOR

Where fuel is both scarce and expensive the utmost economy in its use is required, but when looking around in an industrial centre it can be seen that precious fuel is recklessly blown into the air by a large number of smoking factory stacks.

This waste can easily be stopped by installing a phototube smoke detector. In a small factory where only one engine-man cum stoker was employed, the savings on the fuel bill, after the installation of a smoke detector, amounted to £ 80,- monthly.

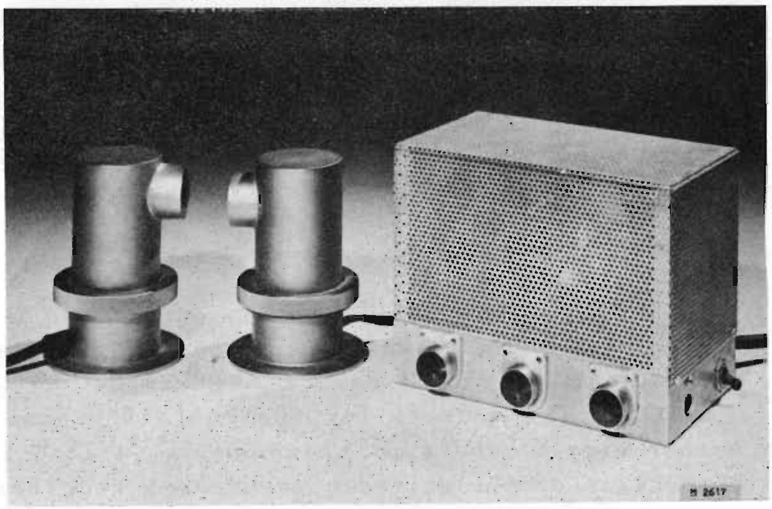


Fig.57. Phototube amplifier for smoke detector with phototube receiver and light projector.

The smoke detector is a simple device. A light projector and a phototube are mounted opposite each other in the funnel uptake or the chimney stack. The phototube commands a relay by means of a sensitive relay amplifier, which may be arranged according to Fig.62. When the light beam is partly or wholly intercepted by smoke, the relay closes and operates a buzzer, warning the man in charge to look after his fire. The phototube and the light projector are mounted in separate housings as shown in Fig.58 and 59. These housings are described in some detail because they are also very useful in other applications where the phototube and the exciter lamp are used outdoors or in a humid atmosphere. Provided sufficient care is taken in the mounting and assembly, they can even be used under water.



Fig.58. Watertight phototube housing.



Fig.59. Watertight light projector.

In one of the housings the phototube is mounted on a circular plate of plexi-glass, the diameter of which is 0.5 mm greater than the inner diameter of the housings. A slit is cut in this plate as shown in Fig.58. The sockets for the phototube base pins are placed on either side of the slit, which ensures a long insulating distance. Both sides of the slit can be pressed together so that the plate fits into the housing and is secured by its own resilience.

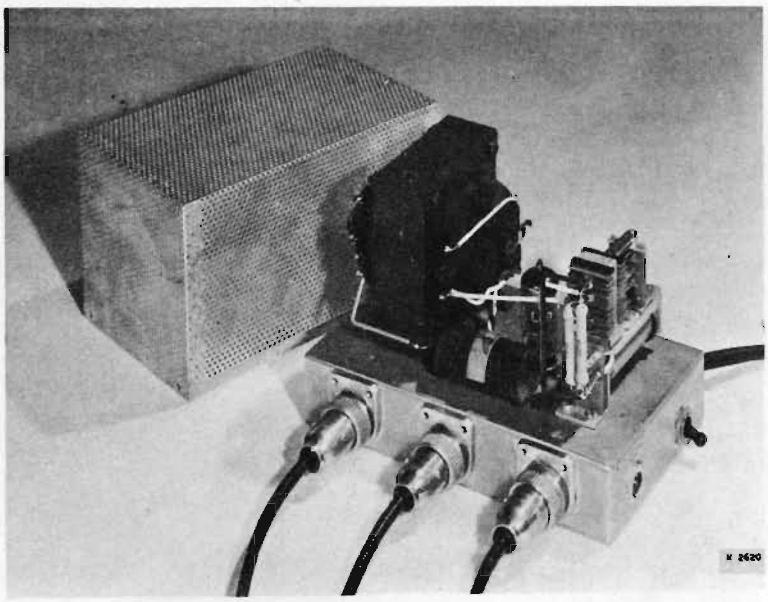


Fig.60. Phototube amplifier for smoke detector with perforated hood removed.

In the light projector (see Fig.59) the fitting for the incandescent lamp is mounted on a plate of insulating material, which is fixed to the bottom of the housing by means of three bolts with spring loading. The lamp can be adjusted by means of nuts, and after adjustment the spiral springs keep the fitting in the right position. The hood of the housing is provided with a window in which a lens or a glass plate can be mounted. Watertight closing is ensured by means of a rubber packing. The hood is fitted on the housing with a ring nut, and a rubber ring in the rim ensures watertightness.

The windows of the light projector and the phototube housing require continuous cleaning. This can be done either by providing for a natural draught or by means of a compressed-air system. Natural draught can be obtained by connecting the light projector and phototube housing to the stack or funnel uptake via tubes

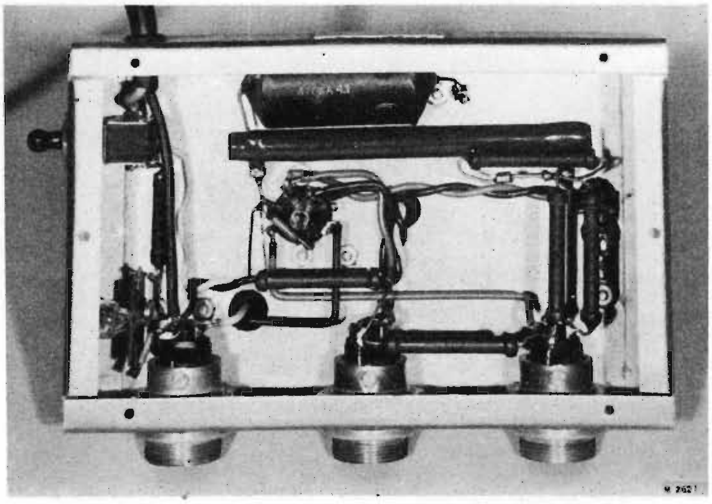


Fig.61. Another view of the amplifier, showing the wiring.

of some length. Near the window holes are drilled in the tube; the draught through the holes passes through the tubes in the direction of the stack, thus keeping the windows free of dust. The compressed-air system consists of an air jet with a narrow slit in the immediate vicinity of the window. By blowing compressed air through the jet at certain intervals, the windows can easily be cleaned.

CIRCUIT DIAGRAM

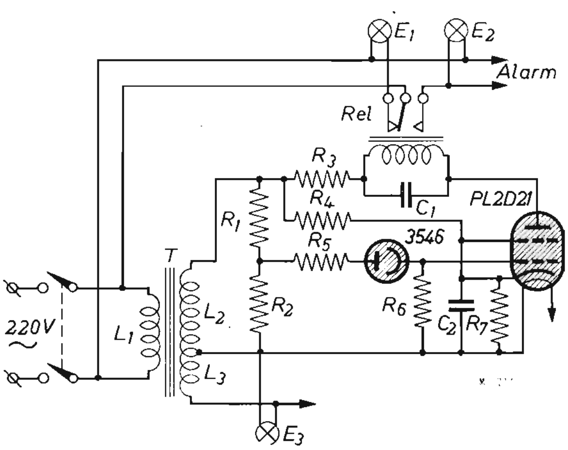


Fig.62. Circuit diagram of the smoke detector.

PARTS LIST

RESISTORS

Circuit ref.	Type	Value	Power rating (W)
R_1	carbon	1 MΩ	1
R_2	carbon	0.4 MΩ	1
R_3	carbon	10 kΩ	2
R_4	enamelled	40 kΩ	5
R_5	carbon	1 MΩ	1
R_6	carbon	1 MΩ	1
R_7	carbon	2.2 kΩ	1

CAPACITORS

Circuit ref.	Type	Value
C_1	paper	0.5 μF
C_2	paper	0.5 μF

TRANSFORMERS AND COILS

T	Mains transformer		
L_1	220 V		
L_2	250 V	40 mA	
L_3	6.3 V	5 A	
Rel	7.6 kΩ		

LAMPS

E_1	Signal lamp green
E_2	Signal lamp red
E_3	Exciter lamp 6.3 V, 3 or 4 A.

AUTOMATIC LEVEL CONTROL

In chemical laboratories and factories it is often required to prevent a liquid in a tank from exceeding a certain level. For this purpose a phototube and exciter lamp can be placed on both sides of a gauge glass, and a relay apparatus can be installed to give an alarm signal when the predetermined level is reached.

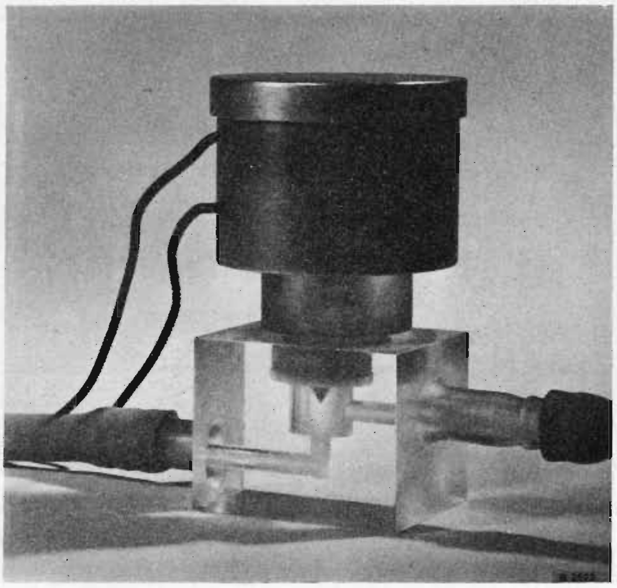


Fig.63. A solenoid valve.

Automatic control is obtained by letting the phototube command a solenoid valve. Such a valve can be fitted either in the liquid supply and made to close when the level is reached, or it can be fitted in the outlet and made to open at the moment the level is exceeded. In the latter case the excess liquid flows off to some other container. A photograph of a solenoid valve is given in fig.63, cross-sectional drawings are shown in figs 64*a*, *b*, *c* and *d*.

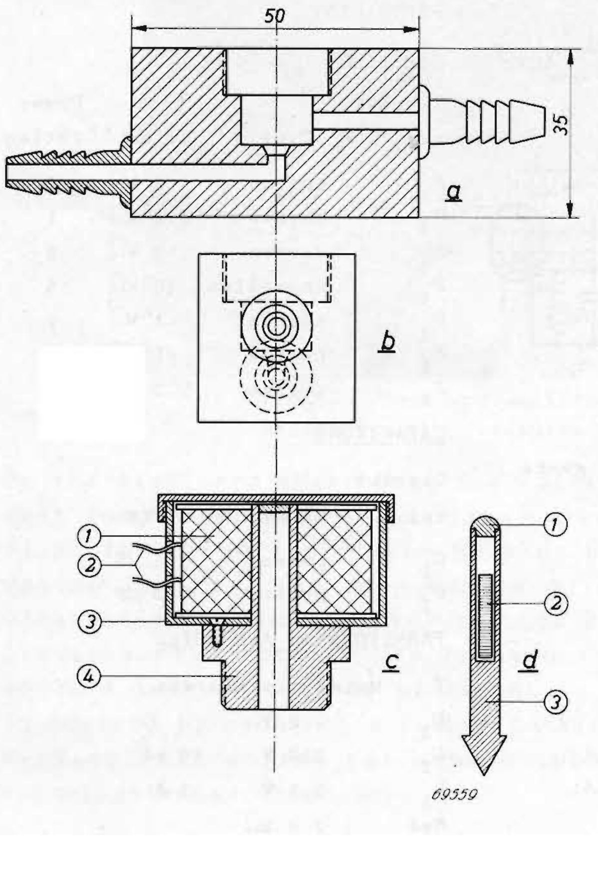


Fig.64. Cross-sectional drawings of the solenoid valve.
a and *b*: the plexi-glass holder;
c: the screw cap wherein 1. the winding, 2. the connection leads, 3. the iron housing, 4. threaded part;
d: the plug, 1. the top plug, 2. the loose iron core, 3. the plexi-glass plug.

In a plexi-glass cube holes are drilled as indicated in the drawing, and hose pillars can be glued to the sides. A screw cap contains a coil wound on a plastic or plexi-glass tube, fitted into the screw cap with a watertight joint. The plug controlling the liquid flow can move up and down in this tube, which is provided with grooves on the inner side to let the liquid pass. The plug is made of a plexi-glass rod, in the top of which an axial hole is drilled to take a loose iron core. The hole is plugged at the top. When the coil is energized the core is attracted, moves upwards and opens the valve suddenly, whilst, when the current in the coil is interrupted, the core drops, the valve is closed and the liquid flow stopped.

In some cases the liquid may be too clear to give sufficient reduction of illumination on the phototube. It is then advisable to use a floating opaque body intercepting the light completely.

The relay-tube switching apparatus as previously described is suitable for operating the valve(see Fig.62).

A PHOTOTUBE AMPLIFIER FOR AUTOMATIC REGISTER CONTROL

In several plants, machinery is used for printing in two or more colours on paper or on textiles; for cutting, folding or gluing already printed paper to bags or wrappings. The material is fed into such machinery from a big roll, and because of irregular drying the material is stretched in some places, whilst in others it has shrunk. Due to these irregularities in the material the machine does not always come into operation at the right instant and this results in part of the production being lost through misprints or miscuttings.

If low-speed machines are used manual control is possible, but in modern high-speed machinery with a production rate up to one thousand items per minute, manual control is too slow in responding to the process; so large parts of the production have to be discarded and materials and time have been lost, while the selection of good and bad products demands extra labour. The electronic register control apparatus described here is fully capable of controlling high-speed machinery. As distinct from the usual apparatus for register control, this circuit uses only high-vacuum tubes; neither gas-filled tubes nor their additional electromagnetic relays are employed. Instead of the latter, use is made of double triodes in Eccles-Jordan circuits.

GENERAL DESCRIPTION

The requirements to be met by equipment for automatic register control may be formulated as follows:
If the material has stretched, the speed at which it is fed into the machine must be accelerated. If the material has shrunk, the speed must be decelerated. If the material is normal, it must move with normal speed.

It is practically impossible to control the speed of a powerful main motor within the time limits concerned. Only a motor with a small rotating mass can be sufficiently controlled in the time available. Therefore the main motor driving the rollers and the press runs at normal speed and is coupled to the machine by means of a transmission gear and to the rollers via a differential gear.

The construction of such a differential gear is schematically shown in Fig.65.

The two gears *A*, *B* are locked on their respective shafts *M*, *E*, which can rotate independently of each other in bearings *G* and *K* of a wormwheel *T* and a mounting frame *F*. The pinion *C* and its shaft can rotate on a bearing in the frame *F*. Suppose that under these conditions the frame *F* is held stationary, while the shaft *M* is driven by the main motor. The motion of gear *A* then causes the pinion *C* to rotate and so the gear *B* is set in motion in the opposite direction of the gear *A*, but with equal speed, the number of teeth on both gears being the same (If rotation in equal direction is desired, supplementary gears can set another shaft in motion.)

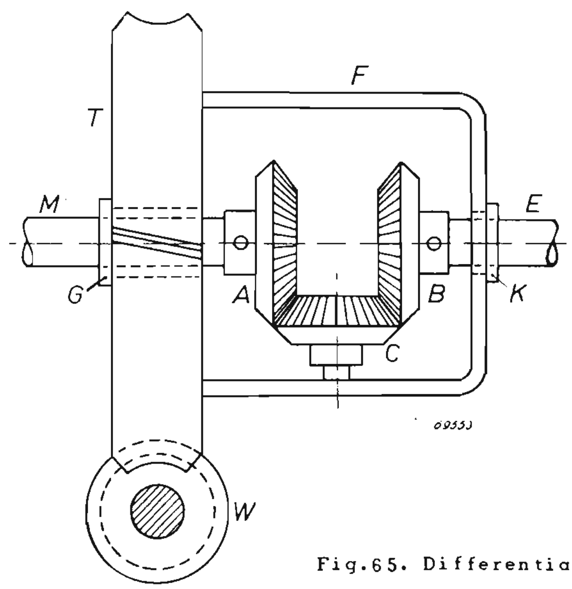


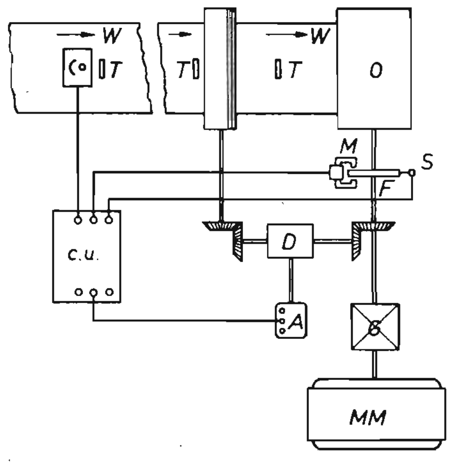
Fig.65. Differential gear.

If, now, the shaft *E* is kept stationary, then rotation of shaft *M* would cause frame *F* and wormwheel *T* to rotate in the same direction with half the speed of *M* if the worm *W* were decoupled. On the other hand, if the shaft *M* rotates and, by means of an auxiliary motor, shaft *W* is rotated in such a way that *T* rotates in the same direction with half the speed of *M*, then the shaft *E* is stationary, whilst, if rotation of shaft *W* sets *T* in motion in opposite direction as *M* with half its speed, the speed of shaft *E* is twice the speed of *M* in opposite direction.

The automatic register control described here is based on this property of a differential gear. For the relatively small errors as originate from shrinking and stretching of the material, it is not necessary that the wormwheel *T* is rotated at such a speed that the shaft *E* is completely stopped or that its speed is doubled. It will suffice to increase or decrease the rotational speed of *E* by a small percentage. Therefore *T* may be driven by a wormshaft connected to the auxiliary motor by means of a reduction gear. The auxiliary motor can be small and of low power. Such a motor can easily be set in motion, stopped or made to reverse.

The auxiliary motor is a d.c. motor with two field coils wound in opposite directions. If one of the field coils is excited, the motor rotates in one direction, if the other field coil is excited

the direction of rotation is reversed. The field excitation is supplied by the electronic control unit. The schematic diagram of the machine is shown in Fig.66.



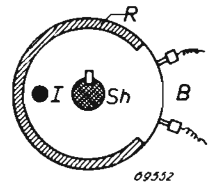


Fig.67. Details of the rotary switch S of Fig. 57.

Fig.66. Schematic diagram of register controlled machine.

The material W is fed into the operational part O of the machine by the roller. Marking spots T are printed on the material, but a significant part of the design can do just as well.

The machine is driven by the main motor MM via a reduction gear G. A fibre disc F operating the switch S and the magnetic pick-up M is mounted on the driving shaft of the machine. Since the switch S has to be closed and opened at a rate of up to 1000 times per minute, any normal switch would have to be replaced once a week. Therefore a special construction is necessary, the details of which are shown in Fig 67. The fibre disc has a copper strip R on part of its circumference. The switch is formed by two carbon brushes and is closed when both brushes are connected via the copper strip. In the disc is an iron pin I serving to excite the magnetic pick-up.

The driving shaft drives the roller via some pinions and the differential gear box D. The speed of the roller can be controlled by the auxiliary motor A. The field coils of this motor are excited by the electronic register control unit CU, this obtaining its commanding signals from the phototube P and from the magnetic pick-up M, whilst it is brought into the control position by the switch S.

Fig.68 is a simplified diagram of the electronic part. This consists of a phototube, a magnetic pick-up, the pre-amplifiers P and M, two double triodes E 80 CC (V_4 and V_{10}) connected in monostable Eccles-Jordan circuits, the so-called flip-flop circuits and

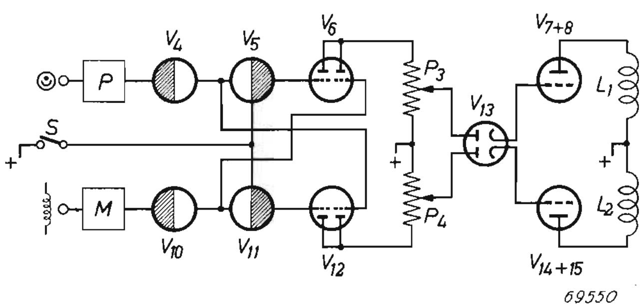


Fig.68. Simplified diagram of the electronic part.

two double triodes E 80 CC (V_5 and V_{11}) connected in bistable Eccles-Jordan circuits. Furthermore, there are two tubes E 80 CC (V_6 and V_{12}) connected in a bridge circuit, whilst the final stage V_{7+8} and V_{14+15} is coupled to the bridge circuit via a double diode 5726, V_{13}. The automatic register control may now be explained with the aid of the figures 66, 67, 68 and the circuit diagram, Fig.79. On the material *W* in Fig.66 marking dots *T* are printed. When these dots pass under the phototube the latter gives a signal to the control grid of the pre-amplifier. This amplifier is connected in such a way that a positive signal from the phototube results in a negative pulse on the grid of the conductive

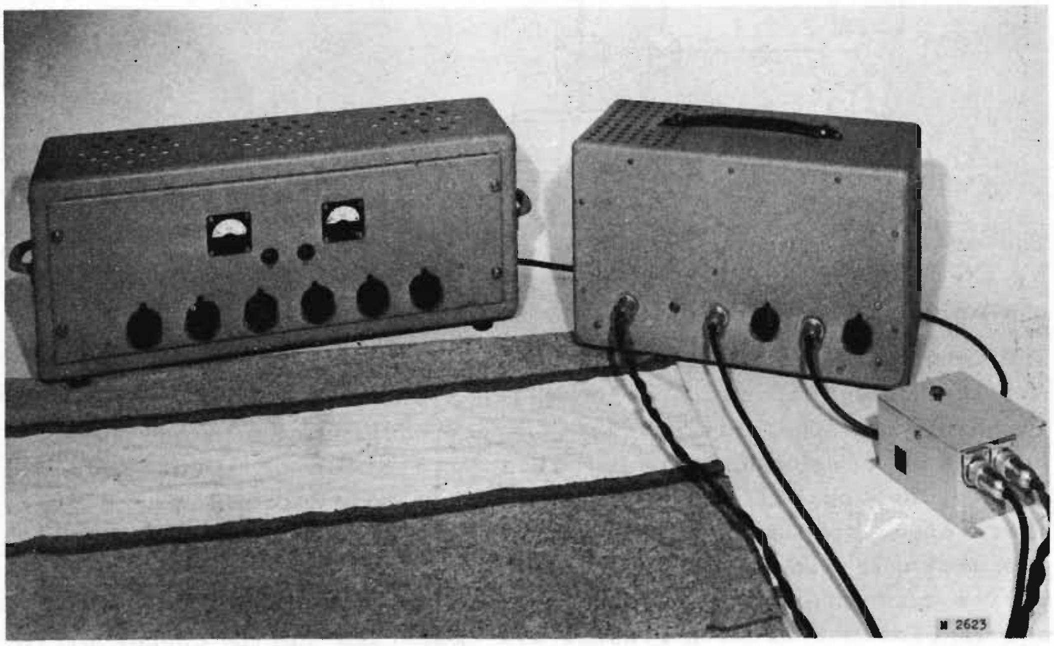


Fig.69. The electronic part of the register control apparatus. *Left:* the electronic control apparatus; *middle:* the phototube amplifier; *right:* the scanner. In the foreground a colour printed blanket; note the marking spot (the dark stripe on the right side).

section of V_4 and causes the flip-flop to reverse. Where V_4 has only one stable position it returns to the initial state immediately, but in the meantime it causes V_5 to reverse, and since the latter has two stable positions it stays reversed. A similar explanation applies to the magnetic pick-up amplifier, to the flip-flop V_{10} and to V_{11}.

The closing of switch S brings V_5 and V_{11} into the initial position and keeps them there, no matter what stray signals might excite their grids. This arrangement blocks the electronic part during the greater part of a revolution of the main shaft and a "dead zone" is provided. Only when the marking spot comes in the vicinity of the phototube, the switch is opened and V_5 and V_{11} can reverse. If no provisions are made for a "dead zone" the machine can successively run at too high a speed, then at too low a speed and so on, this phenomenon being called "hunting". The double triodes V_6 and V_{12} in the bridge circuit are connected to V_5 and V_{11}. The grid of the first section of V_6 is connected to the

grid of the conductive part of V_5 and the grid of the second section to the grid of the non-conductive part of V_{11}. The grids of V_{12} are connected to the remaining sections V_5 and V_{11}.

The anodes of both sections of V_6 and V_{12} are connected in parallel and fed via the potentiometers P_3 and P_4. In the initial position, the two potentiometers carry equal currents and the circuit is in balance. The control grids of the power tubes are connected to the potentiometers via a double diode in such a way that only positive signals can excite the final stage.

After this description of the mechanical and electronic parts the working of the entire apparatus can be explained. The magnetic pick-up is excited by the iron pin in the fibre disc, which at the same time operates the switch S. Both the pin and the switch are connected to the operating part of the machine and thus all three run synchronously.

The phototube is placed in such a position above the material that the marking spots pass at exactly the same moment that the magnetic pick-up gives a negative pulse to its corresponding amplifier. If the material is normal the mark passes the phototube at the same moment that the pulse from the magnetic pick-up is passed to the amplifier; so V_4 and V_{10} receive a negative pulse they reverse and fall back in their initial position. Because the switch S has already been opened a short time beforehand, V_5 and V_{11} are released and the reversal of V_4 and V_{11} causes V_5 and V_{11} to reverse. V_5, V_{11}, V_6 and V_{12} have one cathode resistor in common, the interconnected grids being equally biased. V_6 and V_{12} are in balance when V_5 and V_{11} are in the initial condition. If both double triodes reverse simultaneously, the balance of V_6 and V_{12} is not disturbed and the grids of the final stage are not excited.

If the material has shrunk or stretched, however, then the signals from the phototube and the magnetic pick-up reach the grids of one of the amplifiers. If shrunken material passes, the phototube signal comes first and the grid of V_{7+8} is excited, whilst in the case of stretched material the phototube signal is delayed and the magnetic pick-up signal comes first, exciting the grids of V_{14+15}. Suppose the material has shrunk, then the phototube signal causes V_4 to reverse, V_5 reverses and V_6 is completely blocked, whilst both sections of the double triode V_{12} become conductive. The bridge circuit is then out of balance, so that a positive pulse is applied via the diode to the control grid of V_{7+8}, resulting in the corresponding field coil of the auxiliary motor being excited and the motor rotating in such a way that the rollers are slowed down. After a short time has elapsed the signal of the magnetic pick-up comes in and V_{10} and V_{11} reverse. The balance in the bridge circuit is restored and the voltage on the control grid of V_{7+8} leaks away over the grid resistor. (This is one of the reasons why a diode is employed.) The auxiliary motor slows down but in due course the next signal comes through and the auxiliary motor is accelerated again.

If the material has stretched, the signal from the phototube is delayed. In this case the magnetic pick-up signal comes first and a similar explanation as given above applies, with the result that the control grid of V_{14+15} is excited and the auxiliary

motor rotates in the opposite direction, accelerating the speed of the rollers.

As a rule the error in the material is uniform over comparatively long distances. Therefore, *RC* filters with a large time constant may be employed in the grid circuits of the final stage, while the field coils of the auxiliary motor may be shunted by a capacitor. The result is that the motor rorates with nearly constant speed for the whole of the time during which correction is required. The speed depends on the duration of the pulses in the bridge circuit. If there is only a small interval between the arrival of the signals from the phototube and the magnetic pick-up, the pulses are weak. The longer the interval, the stronger the pulses. The decrease in negative grid bias of the power tubes, and therefore the current in the field coils, is proportional to the duration of the pulses. The peak value of the pulses depends on their duration; their influence on the final stage can be controlled by means of the potentiometers in the bridge circuit.

CIRCUIT DESCRIPTION

The electronic register control apparatus operates with reflected light on the phototubes. Since the surface of the material is not always flat, which causes straying of the reflected beam of light, two phototubes are employed in the scanner. If only one phototube were used, the straying would cause errors in the reading of the phototube. The scanner employed here safeguards the installation against these errors.

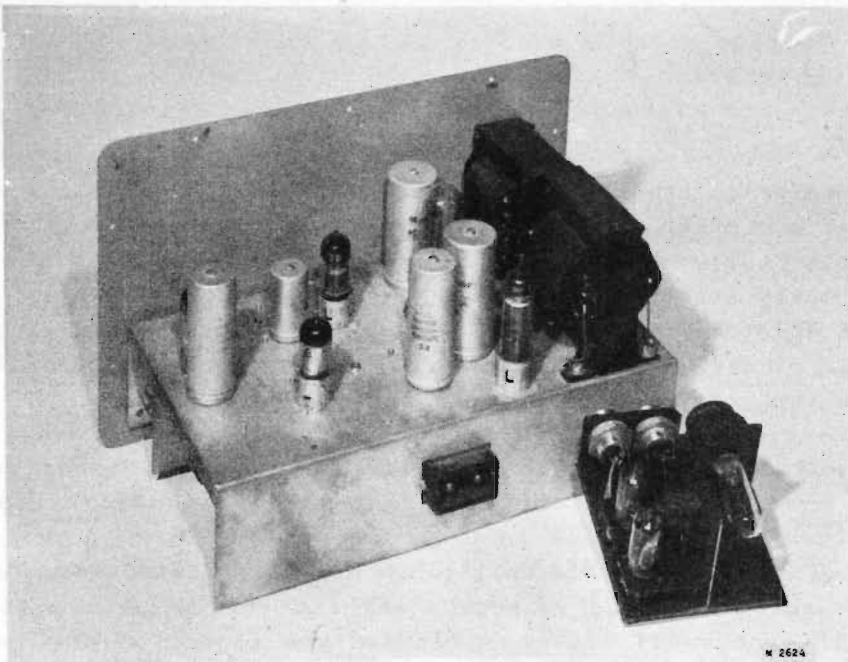


Fig.70. The scanner (right) and the phototube amplifier opened.

In the scanner the two phototubes are mounted very near to each other and the beam of light from the exciter lamp passes between. The lamp is placed in the back part of the box (see Fig.70) and is screened from the phototube compartment. The inner sides of the scanner are painted dull black. There is a hole in the screen for the light beam to pass, and a lens is applied just in front of this hole in the phototube compartment. The beam of light can be focused on the material by means of this lens and it can be adjusted

by a screw on top of the scanner. A photograph of the complete outfit is given in Fig.69 (see also schematic diagram of the electronic part Fig.68).

The cabinet at the left contains the magnetic pick-up amplifier, the flip-flop circuits, the final stage and two supply units (see Figs. 74 and 75). The other cabinet contains the phototube amplifier with supply unit and the rectifier for the exciter lamp (see Figs 70 and 71).

The small box on the right is the scanner (see Fig.69), with the screw for focusing the light beam at the top, and on the left side of the scanner, the window through which the light beam passes and the reflected light enters. In the foreground is a colour-printed blanket, the marking spot on which may be seen at the right side (the dark stripe).

THE PHOTOTUBE AMPLIFIER (Figs 71 and 72)

The signal of the phototubes is a positive pulse with a peak value of 8-15 mV, depending on the contrast between marking spot and background. This signal has the general form as represented in Fig.72*a*. Via a coupling capacitor C_2 and potentiometer P_1 it is applied to the control grid of the pre-amplifier tube E 80 F (V_1), at the control grid of which the pulse has the shape of Fig.72*b*.

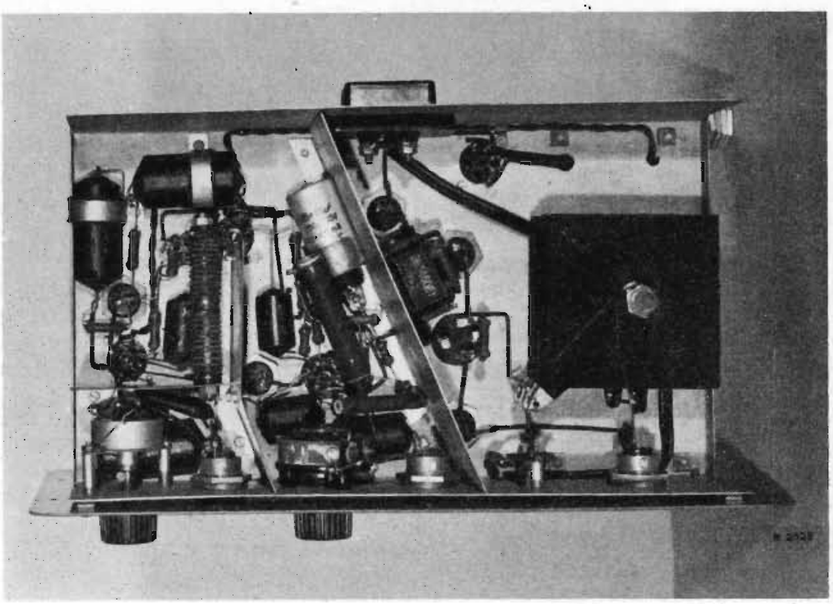


Fig.71. Under-chassis view of the phototube amplifier.

The E 80 F (V_1) is connected normally and the gain of this stage is approximately 180; so the pulse arriving at the control grid of the E 80 F (V_2) has a peak value of approx. 1.5 V to 2.5 V. Since a negative pulse must be amplified, this second E 80 F tube operates without cathode bias, thus using the steepest part of the tube characteristic. Because of the grid current through the resistor R_8 the control grid is biased slightly negatively. The pulse form on this control grid is shown in Fig.72*c*. After due amplification it reaches the grid of the first section of the double triode E 80 CC in the form of a positive pulse as shown in Fig.72*d*. To obtain a pulse with a steep leading edge, as is necessary to operate an Eccles-Jordan flip-flop circuit, the E 80 CC (V_3) is equipped with a cathode resistor P_2 of high value,

adjustable between 4.7 and 14.7 kΩ. In the absence of a signal the tube is in the cut-off position, as a result of which interfering voltages due to coarse material remain below the cut-off point of the tube. The negative pulse reaching the anode of section *I* of the E 80 CC is applied to section *II*, which is connected as a cathode follower with high anode current. A negative pulse with steep leading edge and of a peak value between -60 V and -90V is thus applied to the grid of the conductive section of the flip-flop No.1 (V_4).

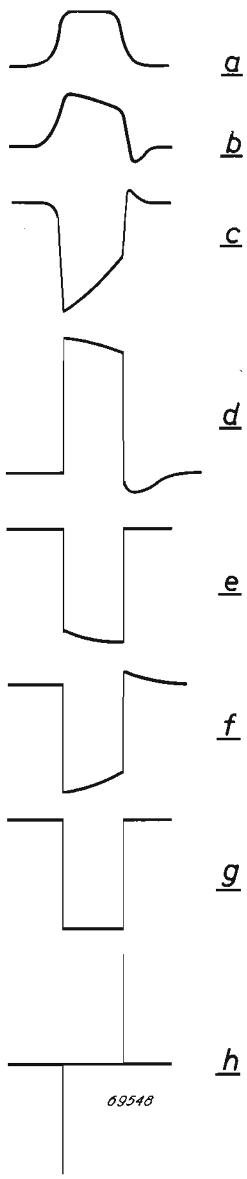


Fig.72. Oscillograms of the phototube signal.

The pulse form on the cathode of the cathode follower is shown in Fig.72e, and Fig.72*f* shows the form in which it reaches the grid of the flip-flop. Fig.72*g* shows the form of the pulse in the anode circuit of the flip-flop, while due to the small value of the coupling capacitor C_{14}, it excites the double triode V_5 in the form of Fig.72*h*.

The power supply unit is built on the same chassis as the amplifier. It has an entirely conventional circuit, employing an EZ 80 as a full-wave rectifier. In addition to the normal choke-capacitor smoothing arrangement, the anode and screen-grid voltages of the pre-amplifier tube and the anode voltage of the phototubes are further smoothed by R_7 and C_5.

The anode voltage of the phototubes is taken from a potential divider consisting of two wire-wound resistors R_1 and R_2 of 0.1 MΩ and 40 kΩ respectively. It is necessary to use wire-wound resistors in the phototube circuit, because resistors of the carbon type would introduce too much noise.

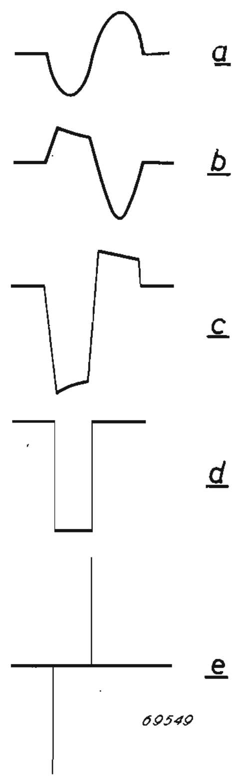


Fig.73. Oscillograms of the magnetic pick-up signal.

THE MAGNETIC PICK-UP AMPLIFIER

The shape of the voltage of the magnetic pick-up approximates a sine curve with a peak value of about 5 V, the negative half cycle being used.

One section of a double triode E 80 CC (V_9) is used for amplification, whilst the other triode section is used for producing a square wave form. To obtain this result, cathode resistors of high value are employed, so that both sections operate in the bend of the characteristic.

The cathode resistor of the first section is shunted by a capacitor of 50 μF. The second section has no by-pass capacitor across the cathode resistor; so negative feedback is applied.

In the first section the anode current is interrupted during part of the negative half cycle of the grid signal, and in the anode circuit a voltage with a square positive half cycle and a sinusoidal negative half cycle appears. In the second section the positive square half cycle is amplified and the negative half sine wave is cut off. A negative pulse with large amplitude is therefore applied to the grid of the flip-flop (V_{10}). The pulse in the anode circuit of the second section of this flip-flop is similar in shape to that in the flip-flop V_4. The wave form in the various stages of the amplifier is shown in Fig.73a to e. The voltage gain of the magnetic pick-up amplifier amounts to approx.18.

THE FLIP-FLOP CIRCUIT

The monostable flip-flop circuits of V_4 and V_{10} are identical and operate under similar conditions. The tubes employed are double triodes E 80 CC. The grid of the conducting section has about the same potential as the cathode, whilst the grid of the non-con-



Fig.74. Back view of the electronic control apparatus.

ducting section is highly negative with respect to the cathode. The grid resistors have such values that the potential of the grid of the first section is about +56 V and that of the second section about +20 V with respect to the chassis. The potential of the cathodes with respect to the chassis is about +56 V. When the conducting section of the double triode is cut off by a negative pulse on the grid, the anode voltage increases suddenly by approximately 130 V. A large positive pulse is therefore applied to the grid of the other section so that this becomes conducting.

This results in a considerable voltage drop in its corresponding anode circuit, so that via C_{14} a negative pulse reaches a common tap on the anode load resistors of both sections of the following bistable Eccles-Jordan circuit. This negative pulse is passed on, via the coupling resistors and capacitors, to the grids. Since the grid of the non-conducting section is already negative, a negative pulse is of no influence. In the conducting section, however, a negative pulse results in the tube being suddenly cut off, the anode voltage increases and the grid of the non-conducting section receives a positive pulse. The double triode reverses and, since the positive peak of the incoming pulse (see Fig.72*h*) is of no influence on such a circuit, it remains reversed until the grid of the non-conducting section becomes positive by the closing of switch S. When this switch closes, a positive voltage from the supply unit reaches the grid of the non-conducting section via R_{42}, R_{34} and R_{32}. The double triode V_5 is returned to its original state and remains so until the switch opens again and the commanding signal from the phototube or the magnetic pick-up reaches the grid of the conducting section of V_5 or V_{11}.

The sections of V_5 and V_{11}, which are non-conducting in the initial position, are shunted by a neon pilot lamp of the type Z10 in series with a 0.5 MΩ resistor. When the switch *S* is closed, the signal lamps light up and show that the double triodes V_5 and V_{11} are in the initial position. Even the opening of the switch may not cause a reversal of V_5 and V_{11}; so the lamps remain burning. However, if a pulse passes through the circuit, V_5 and V_{11} are reversed and the pilot lamps are extinguished.

The cathodes of V_5 and V_{11} and of the double triodes V_6 and V_{12} of the bridge circuit are interconnected and have one common cathode resistor P_5. This resistor may be of the semi-adjustable type and is set at about 6 kΩ.

THE BRIDGE CIRCUIT

The grids of the double triodes of the bridge circuit are connected to the grids of V_5 and V_{11} in the manner already described in the General Description. In the initial condition and when the double triodes V_5 and V_{11} are both reversed, each of the double triodes V_6 and V_{12} has one conducting and one non-conducting section. The anode voltages are then 90 V. If only V_5 or V_{11} are reversed, both sections of one of the double triodes are in the cut-off condition and the other

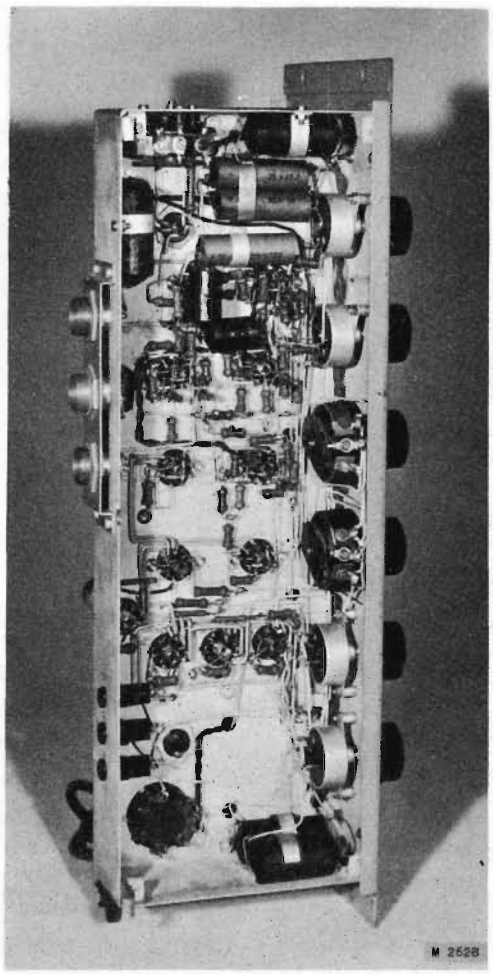


Fig.75. Under-chassis view of the electronic control apparatus.

double triode has two conducting sections. The anode voltages of the tube of which both sections are non-conducting rise to 270 V and the voltage on the conducting tube decreases to 75 V. The voltage drop of 15 V is not important, but the increase in anode voltage of the cut-off double triode results in a pulse of max. 180 V peak value across the potentiometer in the corresponding anode circuit. The duration of the pulse is determined by the time interval between the arrival of the phototube and magnetic pick-up signals.

THE DIODE CIRCUIT AND THE POWER STAGE

Fig.76 is a schematic diagram of one half of the bridge circuit, one half of the double diode 5726 and a power tube with one of the field coils of the auxiliary motor in its anode circuit. The voltage on the capacitor between the bridge circuit and the diode depends on the pulse duration. The shape of the pulses is shown

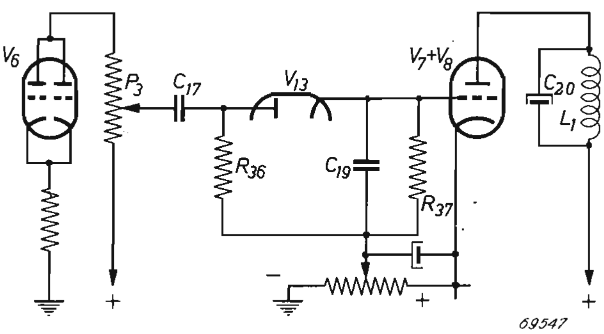


Fig.76. Diagram of one half of the bridge circuit.

in Fig.77*a*, *b* and *c*, for a long, a medium and a short pulse, thus for a large, a medium and a small error in the material. Fig.77*a'*, *b'* and *c'* show the pulse form on the anode of the diode, and the charge of C_{19}, hence the grid-voltage variation of the final stage, is demonstrated by the shape of *a''*, *b''* and *c''*.

As long as the charge of the capacitors is increasing, the diode is conducting, but as soon as the balance in the bridge circuit is restored, the charge on C_{17} leaks away rapidly, while the charge on C_{19} leaks away slowly via R_{37}. This has the effect that the pulses of the double triodes V_5 and V_{11} if they are "translated" to positive grid voltages on the power tubes, are already considerably smoothed. This smoothing is not sufficient, however.

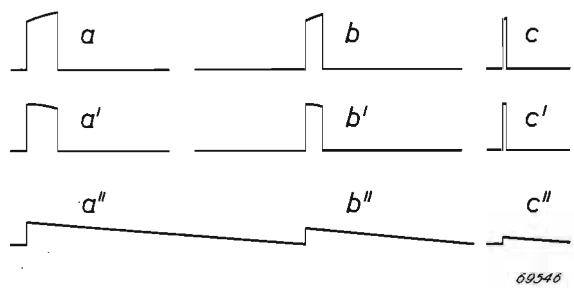


Fig.77. Oscillogram of the pulses in the bridge circuit.

The fault in materials is as a rule uniform over large parts of the material; so when the correcting signal is applied to the power tubes, the auxiliary motor driven by the pulse does not run smoothly, but every time a pulse passes to the power stage, the armature is jerked, which causes heavy wear of the differential.

Therefore additional smoothing is required and this can be obtained by shunting the field coils by electrolytic capacitors of values between 4 μF and 50 μF. This smoothing results in accumulation of a number of corrections, which saves maintenance costs. In the experimental apparatus described here adjustable grid resistors were used, but in various tests made with this outfit it proved that maximum value for these resistors always gave the best results. So in the definite form the apparatus can be provided with fixed grid resistors in the final stage. Adjustments can be made with the potentiometers of the bridge circuit, thus varying the amplitude of the pulse but leaving the smoothing undisturbed. The output stage employs four power pentodes E 80 L connected as triodes. To obtain a high slope and large anode current, two tubes are connected in parallel in each half of the circuit. In order to prevent parasitic oscillations, stopper resistors of 1 kΩ are connected in series with the control grids, and of 100 Ω in series with the screen grids. These resistors must be connected close to the tube sockets.

If there is a considerable error to correct, the power tubes dissipate about 9 W each, and this must be taken into account when considering the location of the tubes on the chassis. The power tubes may not be placed too close to each other or in the immediate vicinity of the power transformers, rectifier tubes or the electrolytic capacitors. In order to reduce the space required, however, two tubes of different halves of the final stage can be placed close to each other, so tube V_7 near to tube V_{14} and tube V_8 near to tube V_{15}.

In the anode circuits milliammeters of 100 mA are inserted to facilitate the adjustment of the apparatus and to obtain information about the error in the material.

Fig.78 shows the grid voltage delivered by the diodes V_D and the anode current I_a of the power tubes as a function of the error. Curves are given for triode connection and for pentode connection

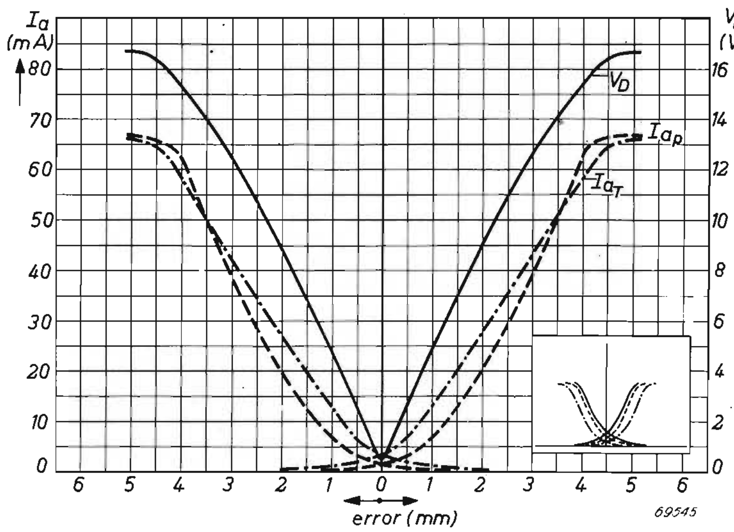


Fig.78. Voltage on the diodes (V_D) and the anode current (I_a) of the power stage, as a function of the error. The curves marked I_{ap} are for pentode connection, those marked I_{at} for triode connection of the power tubes.

of the output tubes. It can be seen that the triode connection is to be preferred, because the slope in the vicinity of the origin of the curve is greater than for pentode connection. Small errors are therefore better corrected when triode connection is used. Another advantage of the triode connection consists in the fact that if a connecting wire to the field coil should be interrupted the tube will not be damaged, the screen grid and anode circuits being interrupted simultaneously. In the case of pentode connection such an interruption would result in overloading of the screen grids.

From the insert of Fig.78 it can be seen that for the correction of small errors it is advantageous not to operate the power tubes in the cut-off position, the slope of the characteristic being rather small at this point. A bias somewhere at the lower bend of the tube characteristics is much more favourable in this respect.

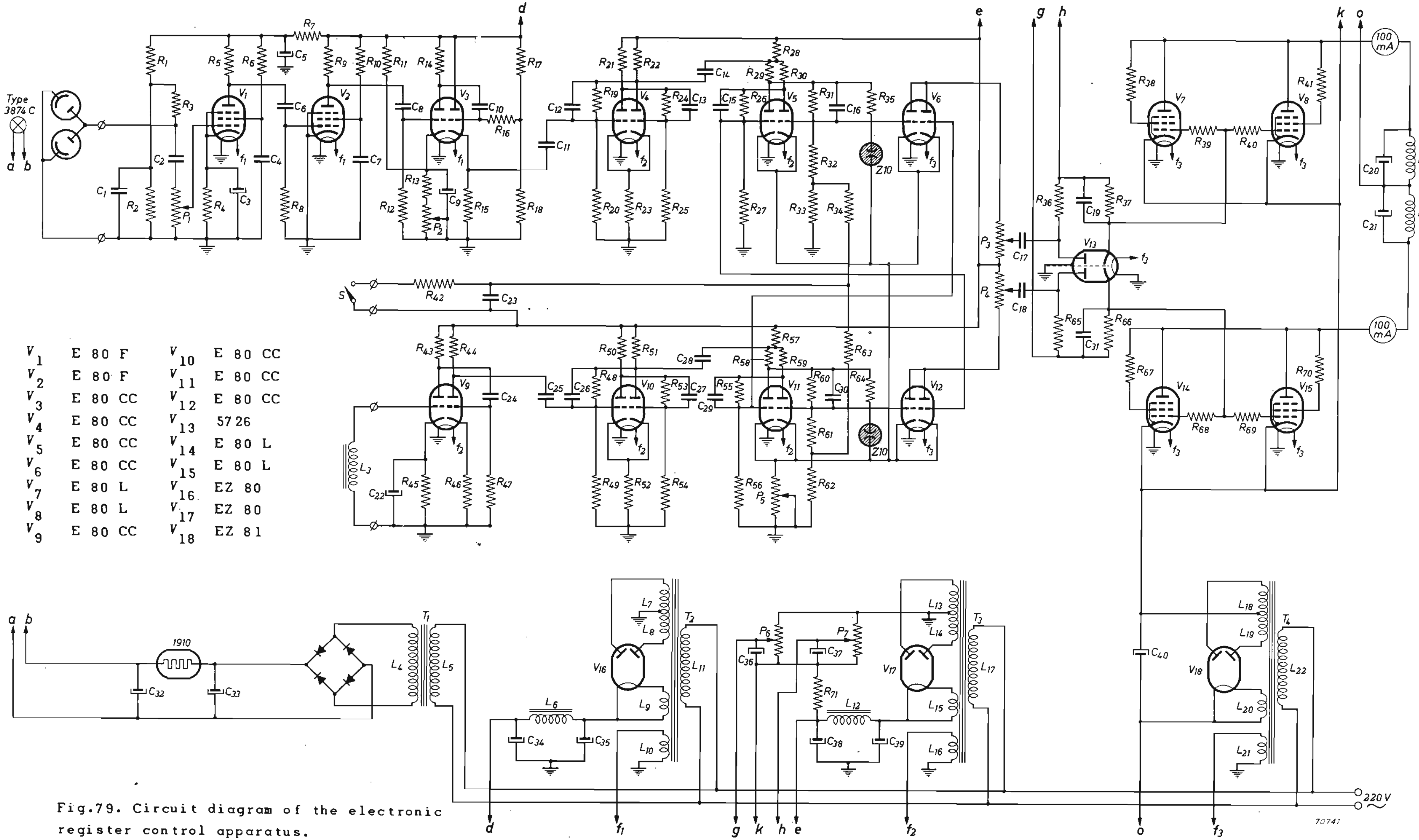
THE SUPPLY UNITS

Two supply units are built together on the same chassis carrying the apparatus just described. One of them, using a rectifier tube EZ 80 in a full-wave circuit, supplies the anode voltage for the magnetic pick-up amplifier, the flip-flop circuits and the bridge circuit. The grid bias for the power tubes is also delivered by this unit. The grid bias can be adjusted, by means of the potentiometers P_6 and P_7, to values between 0 and -20 V and is smoothed by the electrolytic capacitors C_{36} and C_{37} of 50 μF. The heater supply for 5 of the double triodes is delivered by the mains transformer T_3.

The other supply unit is not grounded and is only used for the anode supply of the power stage. A rectifier tube EZ 81 is employed as a full-wave rectifier, and sufficient smoothing is obtained by only one electrolytic capacitor of 50 μF. The double triodes of the bridge circuit, the double diode and the power tubes obtain their heater supply from the transformer of this unit T_4.

THE D.C. SUPPLY FOR THE INCANDESCENT LAMP

In order to avoid ripple in the light source, the incandescent lamp is fed with d.c. Therefore a supply transformer, a selenium rectifier in a bridge circuit, a current stabilizing tube 1910 and two electrolytic capacitors of 2 x 500 μF, 25 V are employed. This supply unit is built on one chassis with the phototube amplifier. With this circuit the current through the lamp is sufficiently smoothed and stabilized to make the intensity of the light beam independent of variations in the mains supply.



V_1	E 80 F	V_{10}	E 80 CC
V_2	E 80 F	V_{11}	E 80 CC
V_3	E 80 CC	V_{12}	E 80 CC
V_4	E 80 CC	V_{13}	5726
V_5	E 80 CC	V_{14}	E 80 L
V_6	E 80 CC	V_{15}	E 80 L
V_7	E 80 L	V_{16}	EZ 80
V_8	E 80 L	V_{17}	EZ 80
V_9	E 80 CC	V_{18}	EZ 81

Fig.79. Circuit diagram of the electronic register control apparatus.

PARTS LIST

RESISTORS

R_{1}	=	0.1 MΩ, 3 W *)
R_{2}	=	40 kΩ, 3 W *)
R_{3}	=	0.1 MΩ, 1 W *)
R_{4}	=	1.8 kΩ, 0.5 W
R_{5}	=	0.27 MΩ, 0.5 W
R_{6}	=	0.82 MΩ, 0.5 W
R_{7}	=	27 kΩ, 0.5 W
R_{8}	=	0.82 MΩ, 0.5 W
R_{9}	=	0.22 MΩ, 0.5 W
R_{10}	=	0.82 MΩ, 0.5 W
R_{11}	=	29 kΩ, 5 W
R_{12}	=	0.82 MΩ, 0.5 W
R_{13}	=	4.7 kΩ, 0.5 W
R_{14}	=	0.1 MΩ, 0.5 W
R_{15}	=	22 kΩ, 5 W *)
R_{16}	=	0.82 MΩ, 0.5 W
R_{17}	=	0.18 MΩ, 1 W
R_{18}	=	0.1 MΩ, 0.5 W
R_{19}	=	0.1 MΩ, 0.25 W
R_{20}	=	47 kΩ, 0.25 W
R_{21}	=	22 kΩ, 0.25 W
R_{22}	=	22 kΩ, 0.25 W
R_{23}	=	6.8 kΩ, 0.25 W
R_{24}	=	0.1 MΩ, 0.25 W
R_{25}	=	22 kΩ, 0.25 W
R_{26}	=	0.1 MΩ, 0.25 W
R_{27}	=	47 kΩ, 0.25 W
R_{28}	=	10 kΩ, 0.25 W
R_{29}	=	22 kΩ, 0.25 W
R_{30}	=	22 kΩ, 0.25 W
R_{31}	=	0.1 MΩ, 0.25 W
R_{32}	=	33 kΩ, 0.25 W
R_{33}	=	12 kΩ, 0.25 W
R_{34}	=	0.1 MΩ, 0.25 W
R_{35}	=	0.5 MΩ, 0.25 W
R_{36}	=	2 MΩ, 0.5 W
R_{37}	=	1 MΩ, 0.5 W
R_{38}	=	100 Ω, 0.25 W
R_{39}	=	1 kΩ 0.25 W
R_{40}	=	1 kΩ, 0.25 W
R_{41}	=	100 Ω, 0.25 W
R_{42}	=	3.9 kΩ, 1 W
R_{43}	=	33 kΩ, 0.25 W
R_{44}	=	0.1 MΩ, 0.25 W
R_{45}	=	4.7 kΩ, 0.25 W
R_{46}	=	4.7 kΩ, 0.25 W
R_{47}	=	0.1 MΩ, 0.25 W
R_{48}	=	0.1 MΩ, 0.25 W
R_{49}	=	47 kΩ, 0.25 W
R_{50}	=	22 kΩ, 0.25 W
R_{51}	=	22 kΩ, 0.25 W
R_{52}	=	6.8 kΩ, 0.25 W
R_{53}	=	0.1 MΩ, 0.25 W
R_{54}	=	22 kΩ, 0.25 W
R_{55}	=	0.1 MΩ, 0.25 W
R_{56}	=	47 kΩ, 0.25 W
R_{57}	=	10 kΩ, 0.25 W
R_{58}	=	22 kΩ, 0.25 W
R_{59}	=	22 kΩ, 0.25 W
R_{60}	=	0.1 MΩ, 0.25 W
R_{61}	=	33 kΩ, 0.25 W
R_{62}	=	12 kΩ, 0.25 W
R_{63}	=	0.1 MΩ, 0.25 W
R_{64}	=	0.5 MΩ, 0.25 W
R_{65}	=	2 MΩ, 0.5 W
R_{66}	=	1 MΩ, 0.5 W
R_{67}	=	100 Ω, 0.25 W
R_{68}	=	1 kΩ, 0.25 W
R_{69}	=	1 kΩ, 0.25 W
R_{70}	=	100 Ω, 0.25 W
R_{71}	=	0.1 MΩ, 1 W

POTENTIOMETERS

P_{1}	=	0.5 MΩ,
P_{2}	=	10 kΩ, 2.5 W *)
P_{3}	=	50 kΩ,
P_{4}	=	50 kΩ,
P_{5}	=	10 kΩ, 2.5 W *)
P_{6}	=	16 kΩ, 2.5 W *)
P_{7}	=	16 kΩ, 2.5 W *)

*) wire-wound
**) ceramic

CAPACITANCES

C_{1}	=	0.47 μF, 500 V
C_{2}	=	400 pF, 500 V
C_{3}	=	50 μF, 12.5 V
C_{4}	=	0.47 μF, 500 V
C_{5}	=	25 μF, 350 V
C_{6}	=	0.1 μF, 500 V
C_{7}	=	0.47 μF, 500 V
C_{8}	=	0.1 μF, 500 V
C_{9}	=	50 μF, 100 V
C_{10}	=	0.1 μF, 500 V
C_{11}	=	0.1 μF, 500 V
C_{12}	=	220 pF, **)
C_{13}	=	220 pF, **)
C_{14}	=	220 pF, **)
C_{15}	=	220 pF, **)
C_{16}	=	220 pF, **)
C_{17}	=	0.47 μF, 500 V
C_{18}	=	0.47 μF, 500 V
C_{19}	=	0.47 μF, 500 V
C_{20}	=	4 to 50 μF, 350 V
C_{21}	=	4 to 50 μF, 350 V
C_{22}	=	50 μF, 12.5 V
C_{23}	=	0.1 μF, 500 V
C_{24}	=	0.1 μF, 500 V
C_{25}	=	0.16 μF,
C_{26}	=	220 pF, **)
C_{27}	=	220 pF, **)
C_{28}	=	220 pF, **)
C_{29}	=	220 pF, **)
C_{30}	=	220 pF, **)
C_{31}	=	0.47 μF, 500 V
C_{32}	=	500 + 500 μF, 25 V
C_{33}	=	500 + 500 μF, 25 V
C_{34}	=	50 μF, 450 V
C_{35}	=	50 μF, 450 V
C_{36}	=	50 μF, 25 V
C_{37}	=	50 μF, 25 V
C_{38}	=	50 μF, 350 V
C_{39}	=	50 μF, 350 V
C_{40}	=	50 μF, 450 V

TRANSFORMERS AND COILS

L_{1}, L_{2}	field coils of auxiliary motor
L_{3}	magnetic pick-up
L_{4}	16 V, 2 A
L_{5}	220 V, 50 ~
L_{6}	choke coil 60 mA, 8 H, 300 Ω
L_{7}, L_{8}	2 x 275 V, 35 mA
L_{9}	6.3 V, 0.6 A
L_{10}	6.3 V, 1.2 A
L_{11}	primary 220 V, 50 ~
L_{12}	choke coil 8 H, 60 mA, 300 Ω
L_{13}, L_{14}	2 x 275 V, 50 mA
L_{15}	6.3 V, 0.6 A
L_{16}	6.3 V, 3 A
L_{17}	primary 220 V, 50 ~
L_{18}, L_{19}	2 x 275 V, 100 mA
L_{20}	6.3 V, 1 A
L_{21}	6.3 V, 4.2 A
L_{22}	primary 220 V, 50 ~

T_{1}	mains transformer for exciter lamp
T_{2}	mains transformer H.T. unit phototube amplifier (T_{1} and T_{2} can be combined)
T_{3}	mains transformer
T_{4}	mains transformer

SUGGESTIONS FOR A SIMPLE SPECTRO-PHOTOMETER

In a laundry experiments were made with diverse machines and washing powders to ascertain the cheapest and most efficient method of washing. Several pieces of fabric were soiled to the same degree and washed in different machines with different washing powders. In the course of the experiment it proved to be difficult to distinguish by eye between the results obtained, and to obtain comparative measurements a kind of photometer had to be developed. A diagram of this photometer is shown in Fig.80.

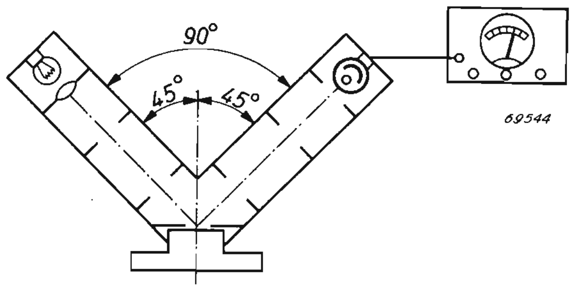


Fig.80. Photometer for comparative measurement of washings.

Two metal tubes are welded to each other at an angle of 90°. One of these tubes comprises the exciter lamp, while the other contains the phototube. Baffles are provided inside the tubes to intercept stray light. The fabric under inspection is stretched over a small steel table with rounded edges and the tubes are placed above it. A suitable meter connected in the phototube circuit gives an indication of the whiteness of the washing. A tablet of magnesium carbonate is used as standard white. This instrument gives very good results. The meter is set to full deflection with the magnesium carbonate block on the exposure table, and the results of the washing experiments are expressed in percentages of this maximum deflection.

Starting from this photometer for comparative measurements it seems only one step further to make a spectro-photometer for comparing the colours of inks, paints or dyes. Suppose a slide with suitable filters is inserted in the tube containing the exciter lamp, then the material under test on the exposure table reflects a certain amount of light in every colour transmitted by the filters. Actually, however, a spectro-photometer is somewhat more complicated than the photometer previously described. First of all, if the angle of reflection is equal to the angle of incidence, gloss of the material under inspection can upset the measurement. Therefore another form must be given to the new instrument.

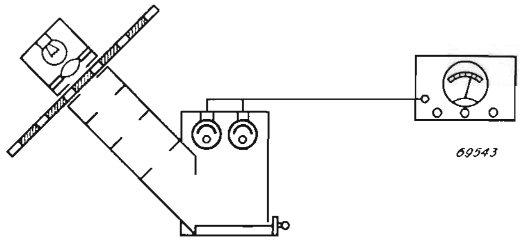


Fig.81. A simple spectro-photometer for comparative measurements.

Furthermore, if only one phototube is used, this is either sensitive in the blue or in the red region of the spectrum. A combination of a blue-sensitive and a red-sensitive phototube is necessary, which can be obtained by connecting two phototubes with different cathodes in parallel (see Fig.81). For colour measurement only the visible part of the spectrum has to be covered, say between 4000 Å and 7000 Å. Therefore a number of selective filters for the different colours of the spectrum must be used. Furthermore, it should be possible to use commercial filters that are easy to obtain. There are several optical industries making good filters for this purpose. The curves for the filters described below were taken from an article by R. Donaldson [1]).

The filters have transmission curves as shown in Fig.82 and are of the following composition:

Filter No.	Colour	Make	Type	Thickness
1	blue	Chance Bros.	OB1	2.5 mm
2	blue-green	Wratten	gelatine filter No. 75	
3	green	Chance Bros. Zeiss	OY 4 plus BG 7	2.1 mm 4,2 mm
4	yellow-green	Chance Bros. " "	OG1 plus cadmium yellow plus cadmium yellow	2.8 mm 1.7 mm 1.4 mm
5	orange	Chance Bros. Corning Chance Bros.	OR 2 plus 978 plus cadmium yellow	2.5 mm 2.9 mm 0.9 mm
6	red	Chance Bros. "	OR 1 plus Calorex	1.8 mm 3.3 mm

In Fig.82 the relative sensitivity of a phototube with the "A" type of cathode (blue-sensitive) and the relative sensitivity of the "C" type of cathode (red-sensitive) are drawn, a curve showing the relative spectral energy distribution of an exciter lamp being also given. From these curves it can be seen that, as a result of the shape of the curve for the exciter lamp, the sensitivity

[1]) R.Donaldson, Proceedings of the Physical Society, page 554/1947.

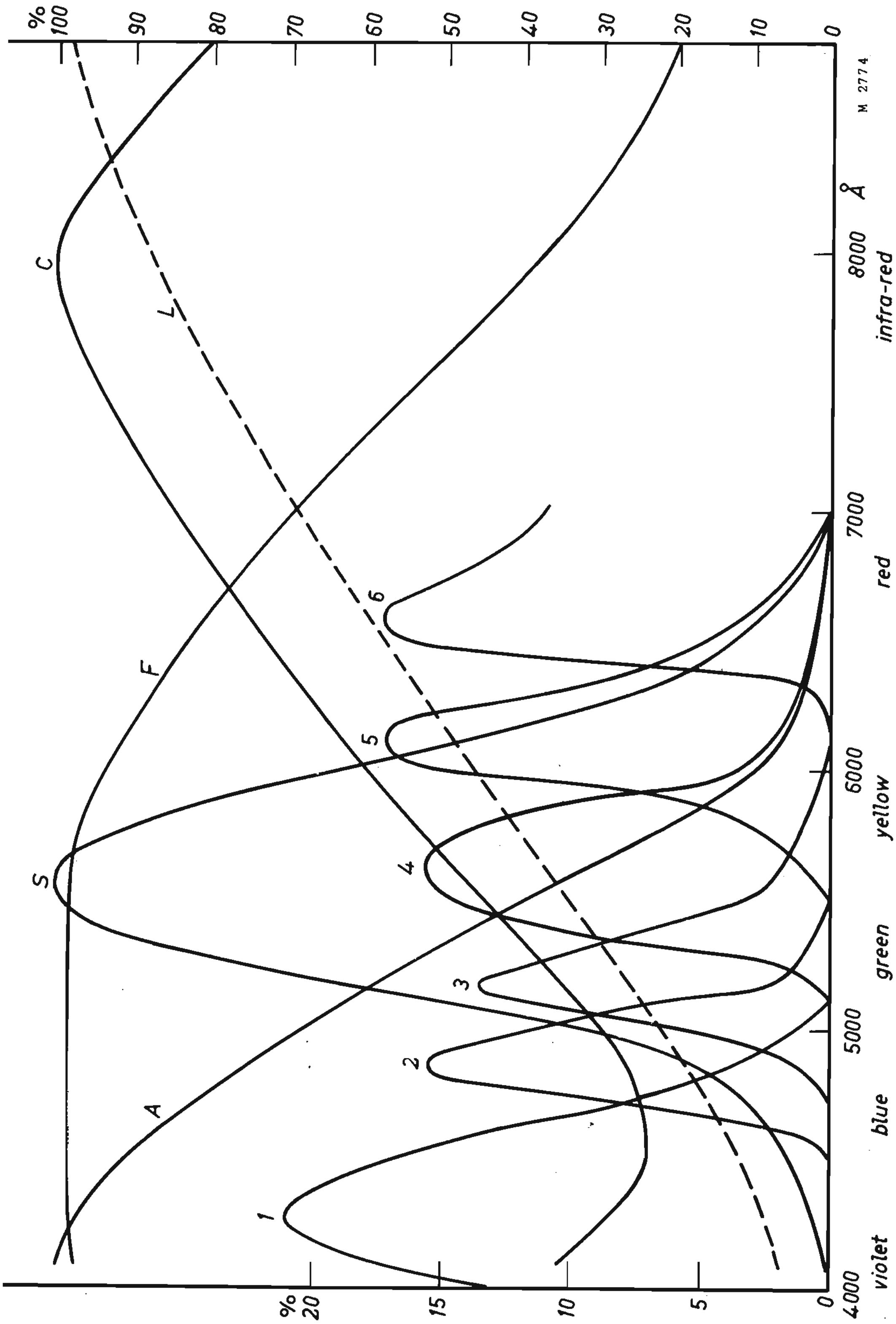


Fig.82.

A: Relative sensitivity of a phototube with A cathode.

C: Relative sensitivity of a phototube with C cathode.

F: Relative transmission curve of the heat absorbing filter.

L: Relative spectral energy distribution of an incandescent lamp with a colour temperature of 2700 °K.

S: Scott BG 19 and relative eye sensitivity curve.

1-6: Relative transmission curves of the selective filters mentioned in the table.

will be low in the blue region and high in the red region of the spectrum. There is a considerable infra-red radiation which can spoil gelatine filters, so a heat absorbing filter must be provided. The Zeiss filter Schott No. BG 19 of 1 mm thickness (the transmission curve of which is drawn in the figure), however, reduces the heat considerably. Other heat absorbing filters are, for instance, the Calorex filters of Chance Bros. With the data obtained from Fig.82 the sensitivity of the spectro-photometer for the six filter wavelengths can be calculated, the result of such a calculation being given in Fig.83. This graph is calculated for the

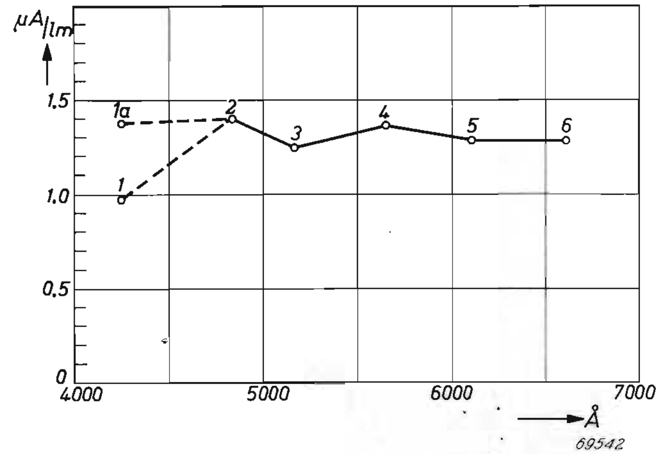


Fig.83. Overall sensitivity of the spectro-photometer described.

use of two phototubes in parallel, viz. the blue-sensitive vacuum phototube 90 AV and the red-sensitive vacuum phototube 90 CV. The first has a sensitivity of 45 μA/lm, whilst the sensitivity of the latter is 20μA/lm, measured with an incandescent lamp with a colour temperature of 2700 °K. The part of the spectral response curve of the 90 CV between 4000 Å and 4800 Å is not always the same for all phototubes of this type. Therefore point No. 1 of the curve may lie on the line between 1 and 1a.

From this graph it can be seen that the sensitivity is sufficiently uniform for comparative colour measurements.

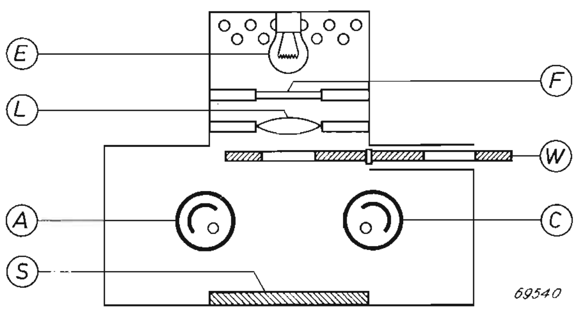


Fig.84. Arrangement of a simple spectro-photometer, for comparative colour measurements.

A possible arrangement for the part of the apparatus so far discussed is shown in Fig.84. The exciter lamp (*E*) is in the top of a well ventilated compartment. The light passes through a heat absorbing filter (*F*) and is focused on the object under inspection by a lens (*L*). A revolving wheel (*W*) contains the six filters that can be placed in the light beam. The lower compartment contains the phototubes (*A* and *C*) and a slide (*S*) on which the material under inspection can be placed. All the inner parts of this com-

partment have to be made dull black. It is also possible to provide a hole in the bottom of the apparatus and to place it over the material under inspection. To prevent stray light from entering the phototube compartment, a rubber ring can be applied to the bottom.

The V.T. voltmeter for use with the apparatus can be made according to the circuit diagram of Fig.85. This circuit has the advantage that the balance of the triode voltmeter is practically independent of variations in the supply voltage. The sensitivity can be adjusted by means of the potentiometer P_2, whilst zero adjustment is made with the potentiometer P_1. Adjustments can be carried out as follows: With an extinguished exciter lamp zero adjustment is made with P_1. Then a block of magnesium carbonate is exposed to the light, and with filter No. 2 inserted, because with this filter the sensitivity is maximum, the pointer of the milliammeter is

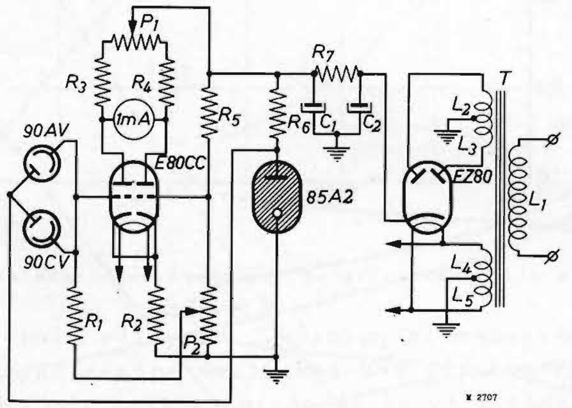


Fig.85. Circuit of the V.T. voltmeter to be used with the spectrophotometer.

PARTS LIST

R_1	6.8 MΩ	1 W	R_7	1 kΩ	1 W	L_1	220	V	
R_2	2.2 kΩ	1 W	P_1	10 kΩ	2.5 W	L_2, L_3	2x250	V	20 mA
R_3	20 kΩ	2.5 W	P_2	10 kΩ	2.5 W				
R_4	20 kΩ	2.5 W	C_1, C_2	2x50 µF	350 V	L_4, L_5	2x3.15	V	2 A
R_5	0.22 MΩ	1 W							
R_6	45 kΩ	2.5 W	Transformer T						

brought to full deflection with P_2. After this adjustment the zero adjustment must be corrected again. If the initial adjustment was very bad the process must be repeated a few times. Colour measurements can now be made with the different filters and the results can be plotted in a graph similar to the one of Fig.83.

The phototubes are fed from a voltage reference tube 85A2. The load resistance is rather high. In the test model of this V.T. voltmeter this value was used, but measurements made with this instrument have shown that sufficient sensitivity can be obtained with a lower value of R_1. A lower value for R_1 reduces the influence of grid current, and a better stability is obtained. Another improvement of the circuit is to include shunt resistance across the milliammeter. This resistor can be interrupted by a press-button switch for obtaining greater sensitivity if meter readings at the lower end of the scale have to be taken. The resistor may have the same value as the meter resistance to obtain double sensitivity.

In this case it may be necessary to use a meter of 250 or 500 μA full scale deflection.

The anode supply is conventional for this type of instrument. A heater type rectifier tube EZ 80 is used, which can be connected to the same heater supply as the double triode.

There are no objections against a.c. supply for the exciter lamp, but it is advisable to use a current stabilizer in series with this circuit. The light source will then be sufficiently constant during the test.

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